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AN IMPROVED PROJECTILE BOATTAIL

PART II

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AN IMPROVED PROJECTILE BOATTAIL. PART II.

Anders S. Platou
George I. T. Nielsen

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ABERDEEN PROVING GROUND, MARYLAND

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A series of projectile boattails have shown improved aerodynamic performance over the standard conical boattail. These boattails have equal or lower drag and an improved gyroscopic stability. Their Magnus and damping characteristics appear to be satisfactory so that the projectile should be dynamically stable. Also, these boattails increase the projectile wheel base considerably, thereby decreasing the balloting in the gun tube. The improved aerodynamic performance could lead to longer ranges, larger payloads, or lower spin rates for future projectiles.

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I. INTRODUCTION

The main purpose of a projectile boattail is to reduce drag, over that of a cylindrical boattailed projectile* (Figure 1), thereby increasing the range of the projectile. In past years various geometric shapes (a conical boattail has been the most popular) have been used to form the boattail and have depended on the reduced base area to reduce the drag. These boattails have worked well in reducing the drag; however, all of them develop a negative lift on the boattail which increases the unstable pitching moment and reduces the gyroscopic stability. These boattails (especially the conical boattail) also generate large Magnus forces and moments at transonic velocities which can adversely affect the dynamic stability of the projectile. Satisfactory gyroscopic and dynamic stability must be maintained so that the average angle of attack remains within low limits as the projectile moves along its trajectory. This permits accurate prediction of the projectile range.

Recently, the BRL has experimented with a series of boattail shapes, which do not have axial symmetry and which have a number of advantages over the axisymmetric boattails. These boattails are formed by cutting the main projectile cylinder with planes, inclined at a small angle to the main projectile axis, such that flat surfaces are created on the boattail. The flat surfaces increase the boattail lift so that the unstable pitching moment is decreased and the drag is reduced by the smaller base area. Also, these boattails have elements of the main cylinder extending to the base which increases the wheel base over that of the axisymmetric boattails. The increased wheel base will reduce gun tube balloting and possibly reduce muzzle jump and gun tube wear. Possible versions of these boattails are:

(1) A boattail formed using four cutting planes so that the base becomes an inscribed square (Figure 2).**

(2) A boattail formed using three cutting planes so that the base becomes an inscribed triangle (Figure 2).**

(3) Boattails formed similar to (1) or (2) but with the cutting plane widths limited so that added lifting surfaces are formed at the base corners (Figure 3).**

(4) Boattails formed similar to (1), (2), and (3) but with cutting planes canted so as to reduce the roll damping during flight (Figure 4).**

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* Previously known as a square base configuration, but changed here to avoid confusion with the new version (1) boattail.

** Patent No. 3,873,048.

(5) A boattail formed by eliminating all of the main body cylinder volume not included inside the volume of two orthogonal wedges (Figure 5).* This version can be extended to zero base area or can be cut off at any station to form a cruciform base.

Characteristics of these new boattails which may be important are:

(1) The flat surfaces generated on the boattails may act as lifting surfaces, thereby increasing the lift on the aft portion of the projectile and decreasing the unstable pitching moment.

(2) All of these boattails have a more gradual reduction in cross sectional area than the conical boattails (Figure 6). This reduces the rapidity of flow expansion over the boattail and may be the reason for the reduction in Magnus forces observed at transonic speeds.

(3) The cylinder elements which extend to the base will form crude rotating fins which should have Magnus forces acting opposite to those on the body[1]. The opposing forces should minimize the resultant Magnus force and moment about the projectile center of gravity.

Aerodynamic tests on these boattail configurations have been made to verify these characteristics and also to find the configuration having the best overall aerodynamic performance. These tests have been run in U.S. Government wind tunnels and ranges which were available to us for these purposes.

II. TEST FACILITIES

The wind tunnel facilities used for the tests so far are:

(1) The NASA Ames Research Center 12 ft. subsonic wind tunnel, M = .5, .7, and .9, 4¼" model, Re/ft = 1.35 to 2.8×10^6 (Re/m = 4.23 to 9.2×10^6).

(2) The Naval Ship Research and Development Center (NSRDC) 7 ft. x 10 ft. transonic wind tunnel, M = .5, .7, .9, .94, and .98, 4¼" model, Re/ft = 2.65 to 4.0×10^6 (Re/m = 8.69 to 13.1×10^6).

(3) The Ballistic Research Laboratories (BRL) 1 ft. supersonic wind tunnel, M = 1.75 to 4.0, 2¼" model, Re/ft = 3.6 to 7.0×10^6 (Re/m = 11.8 to 23.0×10^6).

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* Patent disclosure has been submitted.

1. *Anders S. Platou, "Magnus Characteristics of Finned and Nonfinned Projectiles," AIAA Journal, Vol. 3, No. 1, January 1965, pp. 83-90.*

The range facility used for the tests is:

(1) The Ballistic Research Laboratories (BRL) aerodynamic range, M = .5 to 4.0, 20mm models, atmospheric free flight Reynolds numbers.

III. WIND TUNNEL MODELS

These boattails are being tested using the Army-Navy Spinner Rocket nose and body with the complete configurations being 5, 6, or 7 calibers long.

Two sizes of models, 2¼" (5.715 cm) and 4¼" (10.795 cm) diameters, are required for the wind tunnel tests because of the variation of the tunnel sizes available for the different speed ranges. The models are designed according to the specifications described in reference 2. They consist of a central body mounted on ball bearings and a strain gage balance with various tails and noses attached to the central body. Variations in the lengths of the noses and tails make it possible to test body lengths of 5, 6, or 7 calibers. Tails for each boattail version, listed previously, are made using a 7° cutting plane angle for both the 2¼" and 4¼" diameter models. Also, a straight cylindrical tail and a 1 caliber long 7° conical boattail are available for comparison (Figure 1). Each boattail version can be tested on the 2¼" diameter body with configuration lengths of 5, 6, or 7 calibers; however, the 5 caliber, 4¼" model is limited to the straight cylinder, the conical boattail, and the square boattail. Six and seven caliber, 4¼" diameter models of all of the boattail versions can be tested.

IV. RANGE MODELS

Five caliber long, 20mm diameter, models of these configurations have been fired in the BRL Aerodynamic Range at transonic and supersonic velocities. These models are solid aluminum and have their centers of gravity approximately 60% of the length from the nose. All of the pitching and Magnus moment data have been transferred to the 60% location. The models were launched from two rifled barrels having twists of one revolution in 15.2 calibers and 1 revolution in 19 calibers.

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2. *Anders S. Platou, Raymond Colburn, and John S. Pedgonay, "The Design and Dynamic Balancing of Spinning Models and a Testing Technique for Obtaining Magnus Data in Wind Tunnels," BRL Memorandum Report No. 2019, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, October 1969. AD 699803.*

V. RESULTS AND ANALYSIS

The results presented in this paper compliment, add to, and modify the results presented in reference 3 and present the main aerodynamic results presently available on the new boattails. The results are based on the experimental free flight range and wind tunnel data obtained on the 5 caliber long models. Some data have been obtained on the 6 and 7 caliber wind tunnel models, but these data are not sufficient to give a complete picture. The range flights yield the free flight drag, pitch data, Magnus, roll damping, and pitch damping moments at low angles of attack. The wind tunnel tests yield angle of attack drag*, detailed pitch data, Magnus force and moment over a range of spin and range of angle of attack (-10° to +15°). The data in the main report are presented mainly as faired curves for clarity; however, the detailed data are presented in the appendix of this report for the interested reader.

All of the supersonic wind tunnel data have been obtained using a boundary layer transition strip 1 caliber aft of the nose tip. The transonic tests did not use a trip, but depended on tunnel turbulence or high Reynolds number to trip the boundary layer. Shadowgraphs taken during all of the wind tunnel tests show the boundary layer to be turbulent at least from the base of the nose. The 20mm range models depended on firing conditions to trip the boundary layer so that all of the data presented here are for a turbulent boundary layer over the configuration. Previous tests on smooth wind tunnel bodies without a transition strip have shown that the boundary layer transition can move with spin. This, in some cases, results in nonlinear variations in the Magnus characteristics with spin.

The zero angle of attack drag coefficient, C_{D_0}, for the various boattails are compared in Figure 7. The triangular boattail has the lowest drag while the square boattail has a drag near the conical boattail. The cruciform boattail has the highest drag of all the configurations at supersonic speeds which is apparently due to low base pressures. The high drag rules out the use of the cruciform tail for long range projectiles; however, its low drag at high subsonic speeds and its relatively high stability, as explained later, at all Mach numbers may make it useful for other purposes.

3. *Anders S. Platou, "An Improved Projectile Boattail," BRL Memorandum Report No. 2395, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, July 1974. AD 78[illegible]20. Also, AIAA Paper No. 74-779, AIAA Mechanics and Control of Flight Conference, Anaheim, California, 5-9 August 1974.*

* Some wind tunnel drag data are available, but breakage of drag balances due to model spin resonance with the drag link has caused severe problems in obtaining drag data with the model spinning.

The lower drag of the triangular boattail at supersonic speeds is probably due mainly to the smaller base area. However, recent supersonic wind tunnel tests have shown that the triangular boattail has a higher base pressure than the conical boattail, thereby indicating lower viscous losses in the boattail flow.

The geometric asymmetry of the triangular boattail may also decrease the drag at low angles of attack. At zero spin the asymmetry produces an asymmetric drag polar (Figure 8), so that drag values at constant angle of attack with spin will be the average drag between plus and minus angles of attack. It appears that this will decrease C_{D_α}, at least at low angles of attack; however, this thought has not been thoroughly investigated due to strain gage balance difficulties.

The first transonic wind tunnel tests at Ames and NSRDC and a few free flight tests at transonic velocities showed that the drag of the added lifting surface version (Figure 3) is considerably higher than that of versions 1 or 2 (Figure 2). This plus the minimal increase in stability have curtailed further testing of version 3 to a later date.

The wind tunnel tests have shown some variation of drag with spin on the new boattails (Figure 9). The straight boattails have minimum drag at zero spin while the twisted boattails have minimum drag at the twist rate. Again, the available data to confirm these results are limited due to mechanical failure of the drag balance.

The gyroscopic stability of a projectile is directly proportional to the spin squared and inversely proportional to the aerodynamic pitching moment.* Since stable flight of a projectile requires that the gyroscopic stability remain above 1, it behooves the designer to select a projectile shape having the best pitching moment. Conical boattails reduce the normal force (Figure 10) and increase the unstable pitching moment, especially at transonic velocities (Figure 11). However, as seen in Figures 10, 11, and 12, the new boattails not only reduce the unstable pitching moments at all Mach numbers below that of the conical boattail, but at all supersonic Mach numbers of interest reduce the pitching moment over that of the cylindrical tail. For the first time in artillery projectile design we can employ a boattail which not only decreases drag, but also increases the stability of the projectile. This could aid projectile design, for, in most instances, the projectile design is governed by the maximum unstable pitching moment attained at any Mach number within the projectile flight envelope.

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* All presented pitching moments are about a C.G. located 60% of the body length aft of the nose.

Some interest has been shown in comparing these boattails to a conical boattail with fins or strakes. However, a direct comparison is impossible with previous data since the finned boattails have been tried on other projectile shapes. To obtain a direct comparison a 1 caliber long, 7° conical boattail with 4 in-caliber fins was tested on the 2¼" wind tunnel model at supersonic speeds. The results (Figures 10 and 11) show that the finned conical boattail has about the same normal force and pitching moment as the square boattails. The finned boattail drag will be greater than the bare conical boattail due to the additional fin drag.

One of the aerodynamic problems of the new boattails is the high roll damping inherent in the straight configurations. Roll damping moment coefficients up to -.1 were measured during the range flights and this is sufficient to despin a typical projectile to instability during flight. To circumvent this, it is necessary to twist or cant the boattails so that spin will be maintained during the flight. Range firings of these boattails with 0 and 1/15 (rev/cal) twists yield the following rolling moments.

	C_{ℓ_p}	C_{ℓ_δ}
Square Boattail	-.055	+.037
Triangular Boattail	-.098	+.084
Cruciform Boattail	-.073	+.063
Conical or Cylindrical Boattail	-.015	0

Even though it is not possible to theoretically predict the Magnus force on a projectile, it is possible by studying shadowgraphs and analyzing the force and moment test results to visualize the mechanisms producing the Magnus force. The picture which is visualized is that of an aerodynamic body composed of the actual projectile body surrounded by a warpable, viscous, aerodynamic body made up of the boundary layer.

At all Mach numbers the Magnus force is generated to a large extent by the shape of the boundary layer, and the shape in turn is influenced greatly by the viscous twist or warpage due to the projectile spin (reference 4). At zero angle of attack the warpage of the boundary layer due to spin is axisymmetric about the main centerline, so that the resulting aerodynamic forces and moments are zero except for drag and rolling moment. At small angles of attack, the boundary layer thickens on the lee side of the body, but at zero spin the boundary layer maintains mirror symmetry. A normal force and pitching moment are generated, but the side forces and moments remain zero. With spin

the thickened portion of the boundary layer twists in the direction of spin, all symmetry is destroyed, and a side force and moment are generated.

If a conical boattail is used in place of the cylindrical tail, at subsonic or transonic velocities, the boundary layer thickens due to the flow expansion over the boattail. The thicker boundary layer is distorted more by spin and a larger Magnus force is created (Figure 13 and reference 5). At supersonic speeds the Prandtl-Meyer expansion over the conical boattail holds the boundary layer to thinner values so that large increases in Magnus force do not occur. The large increase in Magnus force and moment caused by the conical boattail at transonic velocities may be sufficient to destabilize an already marginally (gyroscopic) stable projectile (reference 6) by causing large changes in dynamic stability.

Wind tunnel and range tests on the new boattails indicate that no large Magnus forces and moments are generated at any of the tested Mach numbers (Figure 13). The wind tunnel tests at $M > 1$ show the Magnus forces and moments to be linear over the spin range tested (Figure 14) and approximately linear over an angle of attack range of at least $\pm 3^\circ$ (Figure 15)*. When nonlinearities do occur they appear to be in the direction of decreasing Magnus force and moment.

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4. *J. C. Martin, "On Magnus Effects Caused by Boundary Layer Displacement Thickness on Bodies of Revolution at Small Angles of Attack," BRL Report No. 870, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, June 1955. AD [illegible]2055.*

5. *George I. T. Nielsen and Anders S. Platou, "Effect of Boattail Configuration on the Magnus Characteristics of a Projectile Shape at Subsonic and Transonic Mach Numbers," BRL Report No. 1720, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, June 1974. AD 921823L.*

6. *C. H. Murphy, "Free Flight Motion of Symmetric Missiles," BRL Report No. 1216, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, July 1963. AD [illegible]2757.*

* Additional subsonic and transonic wind tunnel tests must be run to verify this at the lower speed ranges. The subsonic and transonic wind tunnel tests run to date have given sketchy Magnus results due to the high sensitivity of Magnus characteristics to tunnel turbulence and flow inclination.

The side force generated on the twisted boattails modifies the above boundary layer picture appreciably and results in smaller Magnus forces.* At small angles of attack and zero spin the boundary layer is distorted by the twist in the opposite direction from the intended spin. For a right hand twist the thick or lee side of the boundary layer twists to the left and creates a side force to the right. When the body spins in the direction intended or caused by the twist a Magnus force is generated to the left (Figure 14). This was also noticed by M. Sylvester in reference 7. As the spin increases, the combined side force changes sign so that at typical projectile spin rates the side force is less than on a straight boattail configuration. From Figure 14 it can be seen that for a given α the side force and moment for a twisted boattail can be expressed as:

$$C_Y = C_{Y_o} + C_{N_p} \frac{pd}{V}$$

$$C_n = C_{n_o} + C_{m_p} \frac{pd}{V}$$

where C_{Y_o} and C_{n_o} are the zero spin offsets at each angle of attack and C_{N_p} and C_{m_p} are the Magnus slopes at each angle of attack. These have been determined from wind tunnel tests (Figure 16) at supersonic speeds. It can also be seen that $C_{N_{p_\alpha}}$ and $C_{m_{p_\alpha}}$ are spin dependent (Figure 17) for the twisted configurations and must be evaluated for

7. *Maurice A. Sylvester, "Wind Tunnel Magnus Tests of Cylindrical and Boattail Army-Navy Spinner Projectiles with Smooth Surface or 20mm Equivalent Engraving (Rifling Grooves)," BRL Report No. 1758, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, February 1975. AD B002628L.*

* Figure 16 of reference 3 is in error. At the time these data were taken, the offsets, a and b, mentioned in this paragraph were not measured.

all spin rates (pd/V) encountered during flight. References 8 and 9 present Magnus data on finned boattail configurations. Even though these data show fins reduce the Magnus properties, they do not indicate the zero spin offset shown by the BRL data.

Aerodynamic pitch damping measurements have been limited to range data and indicate that the aerodynamic damping is independent of the configuration (Figure 18). This is surprising for the lifting surfaces on the new boattails should increase the pitch damping. No pitch damping data are available on a corresponding finned boattail configuration; however, unpublished data on the Navy 5 inch/54 projectile with and without boattail fins show the same degree of damping. Possibly the longer 6 or 7 caliber configurations will show a difference in the damping coefficient when they are tested.

VI. CONCLUSIONS

The aerodynamic data obtained show that all of the new boattails change the aerodynamic characteristics of a projectile considerably.

(1) The new boattails improve the pitching moment of projectiles over that of the conical boattail.

(2) The square boattail has about the same drag reduction as the conical boattail.

(3) The cruciform boattail drag is too high and eliminates it as a viable configuration.

(4) The twisted triangular boattail has the best aerodynamic properties for projectiles. It has the lowest drag, good pitching moments, and low Magnus moments for good stability.

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8. *Leroy M. Jenke, "Experimental Magnus Characteristics of Ballistic Projectiles With and Without Anti-Magnus Vanes at Mach Numbers 1.5 Through 2.5," AEDC-TR-73-162; AFATL-TR-73-188; von Karman Gas Dynamics Facility, Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, Tennessee, December 1973.*

9. *Leroy M. Jenke and Jack B. Carman, "Experimental Magnus Characteristics of Ballistic Projectiles With Anti-Magnus Vanes at Mach Numbers 0.7 Through 2.5," AEDC-TR-73-126; AFATL-TR-73-150; Propulsion Wind Tunnel Facility, Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, Tennessee, December 1973.*

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1. Anders S. Platou, "Magnus Characteristics of Finned and Nonfinned Projectiles," *AIAA Journal*, Vol. 3, No. 1, January 1965, pp. 83-90.

2. Anders S. Platou, Raymond Colburn, and John S. Pedgonay, "The Design and Dynamic Balancing of Spinning Models and a Testing Technique for Obtaining Magnus Data in Wind Tunnels," BRL Memorandum Report No. 2019, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, October 1969. AD 699803.

3. Anders S. Platou, "An Improved Projectile Boattail," BRL Memorandum Report No. 2395, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, July 1974. AD 785520. Also, AIAA Paper No. 74-779, AIAA Mechanics and Control of Flight Conference, Anaheim, California, 5-9 August 1974.

4. J. C. Martin, "On Magnus Effects Caused by Boundary Layer Displacement Thickness on Bodies of Revolution at Small Angles of Attack," BRL Report No. 870, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, June 1955. AD 72055.

5. George I. T. Nielsen and Anders S. Platou, "Effect of Boattail Configuration on the Magnus Characteristics of a Projectile Shape at Subsonic and Transonic Mach Numbers," BRL Report No. 1720, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, June 1974. AD 921823L.

6. C. H. Murphy, "Free Flight Motion of Symmetric Missiles," BRL Report No. 1216, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, July 1963. AD 442757.

7. Maurice A. Sylvester, "Wind Tunnel Magnus Tests of Cylindrical and Boattail Army-Navy Spinner Projectiles with Smooth Surface and 20mm Equivalent Engraving (Rifling Grooves)," BRL Report No. 1758, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, February 1975. AD B002628L.

8. Leroy M. Jenke, "Experimental Magnus Characteristics of Ballistic Projectiles With and Without Anti-Magnus Vanes at Mach Numbers 1.5 Through 2.5," AEDC-TR-73-162; AFATL-TR-73-188; von Karman Gas Dynamics Facility, Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, Tennessee, December 1973.

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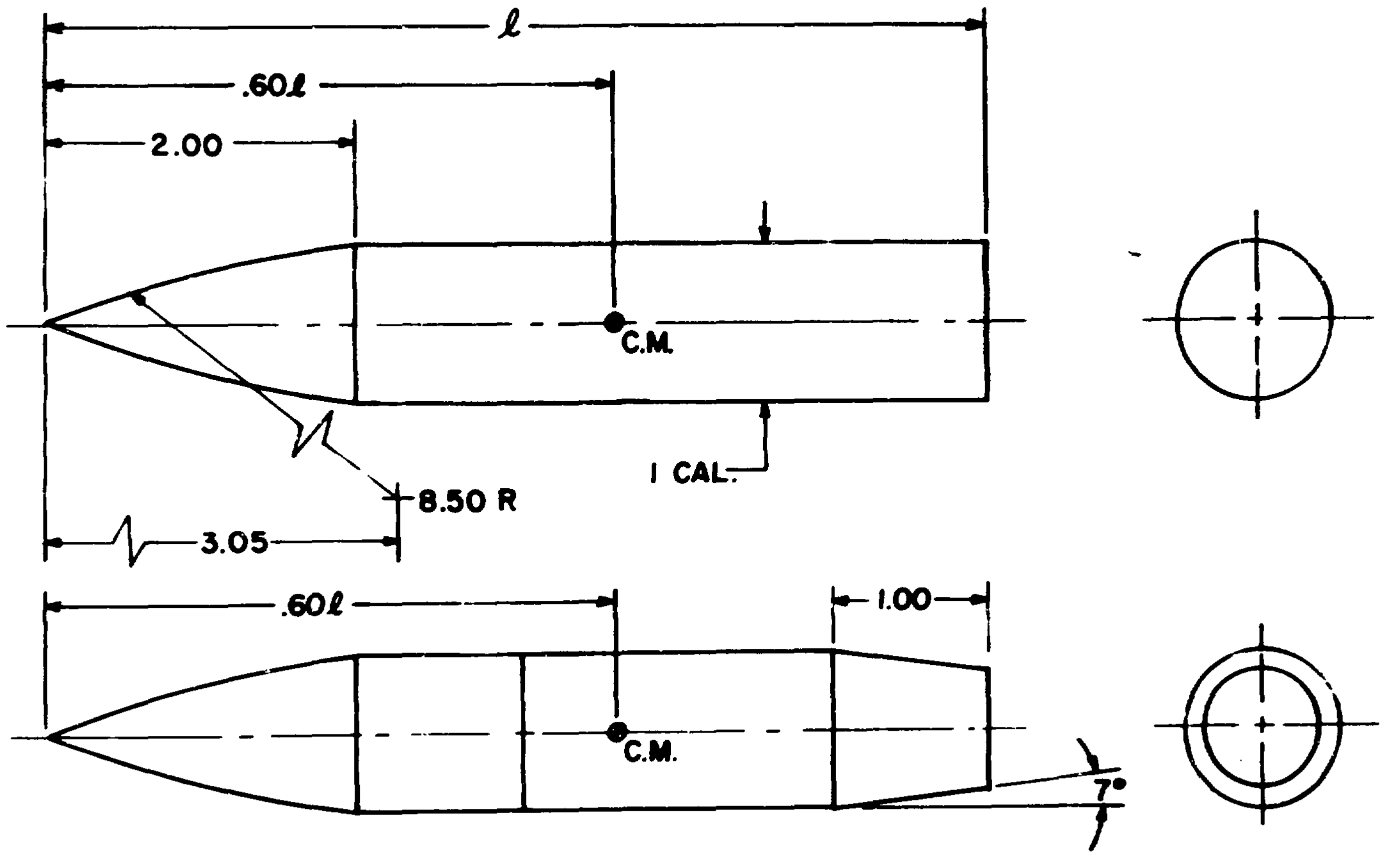

Figure 1. The Cylindrical and Conical Boattail, Dimensions in Calibers, ℓ = 5, 6, or 7 calibers

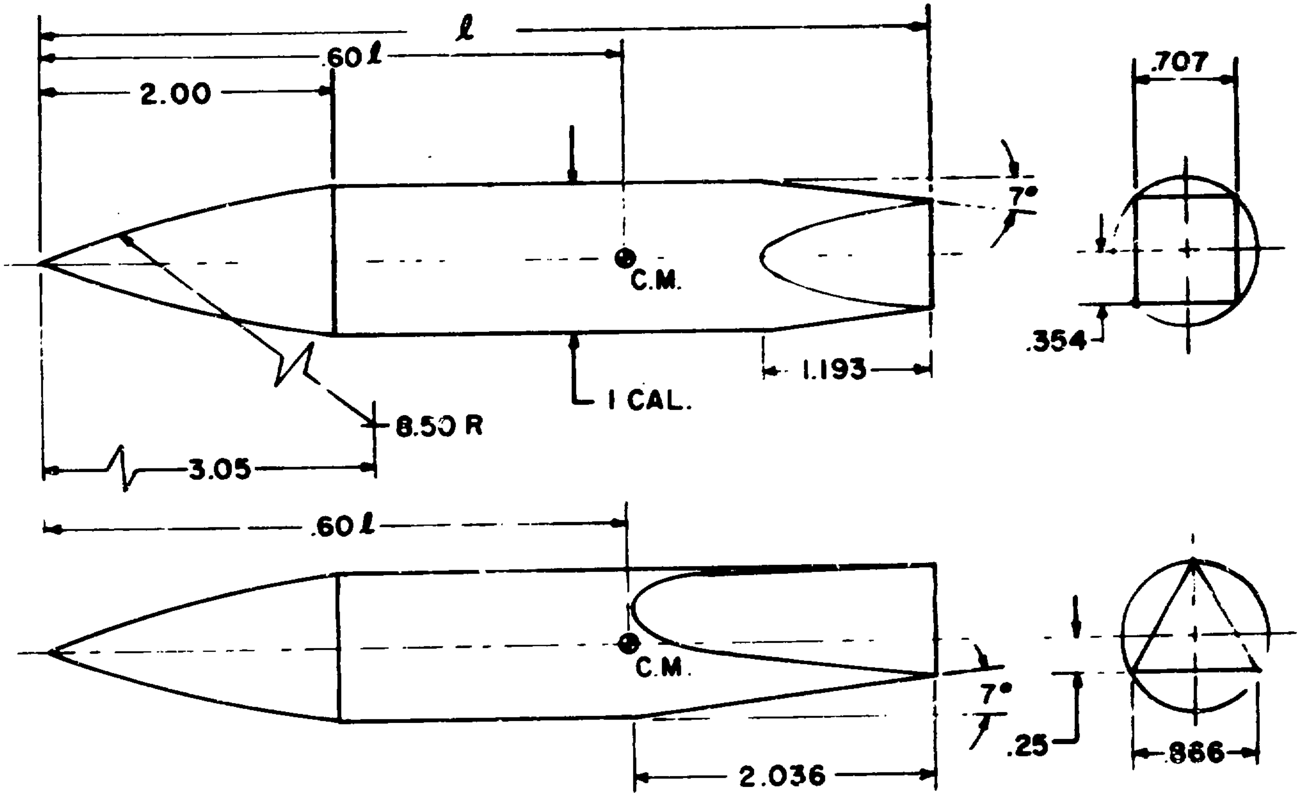

Figure 2. The Square and Triangular Boattail, Dimensions in Calibers, ℓ = 5, 6, or 7 calibers

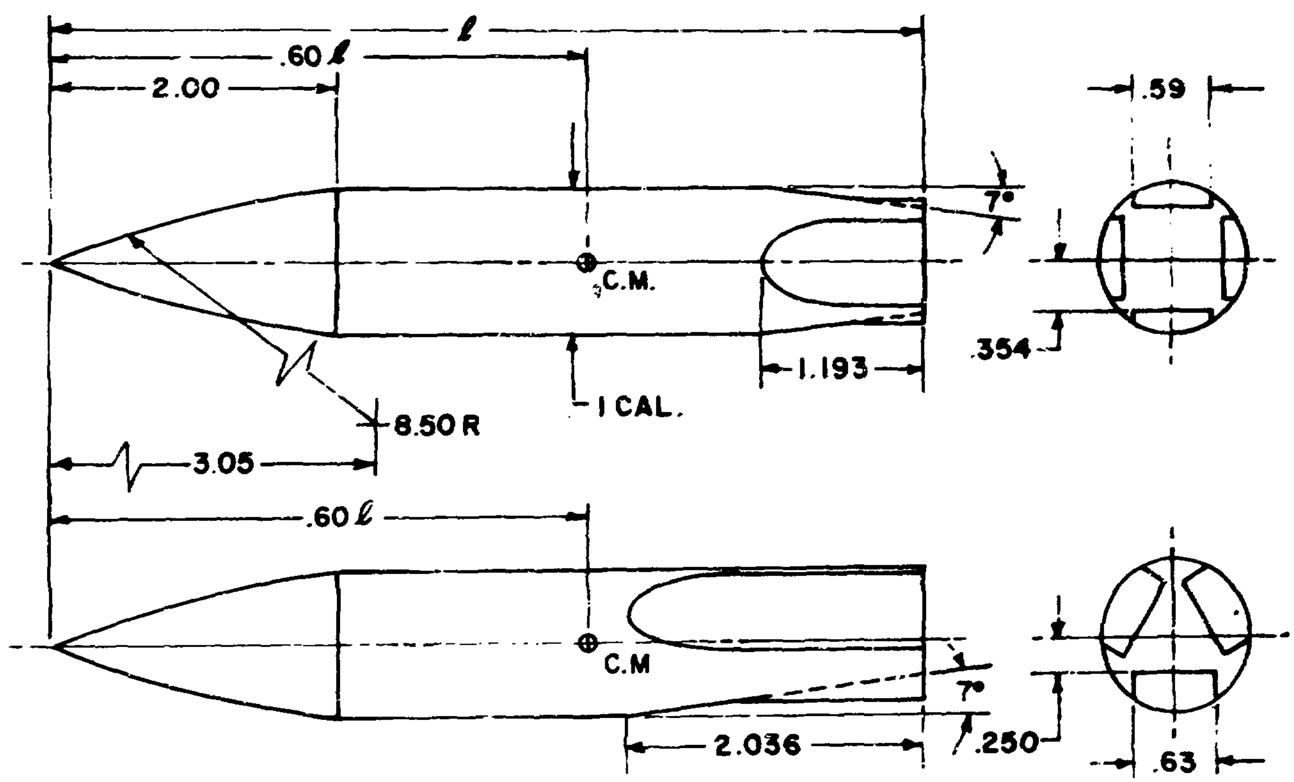

Figure 3. The Added Lifting Surfaces, Dimensions in Calibers, ℓ = 5, 6, or 7 calibers

Figure 4. A Canted Boattail

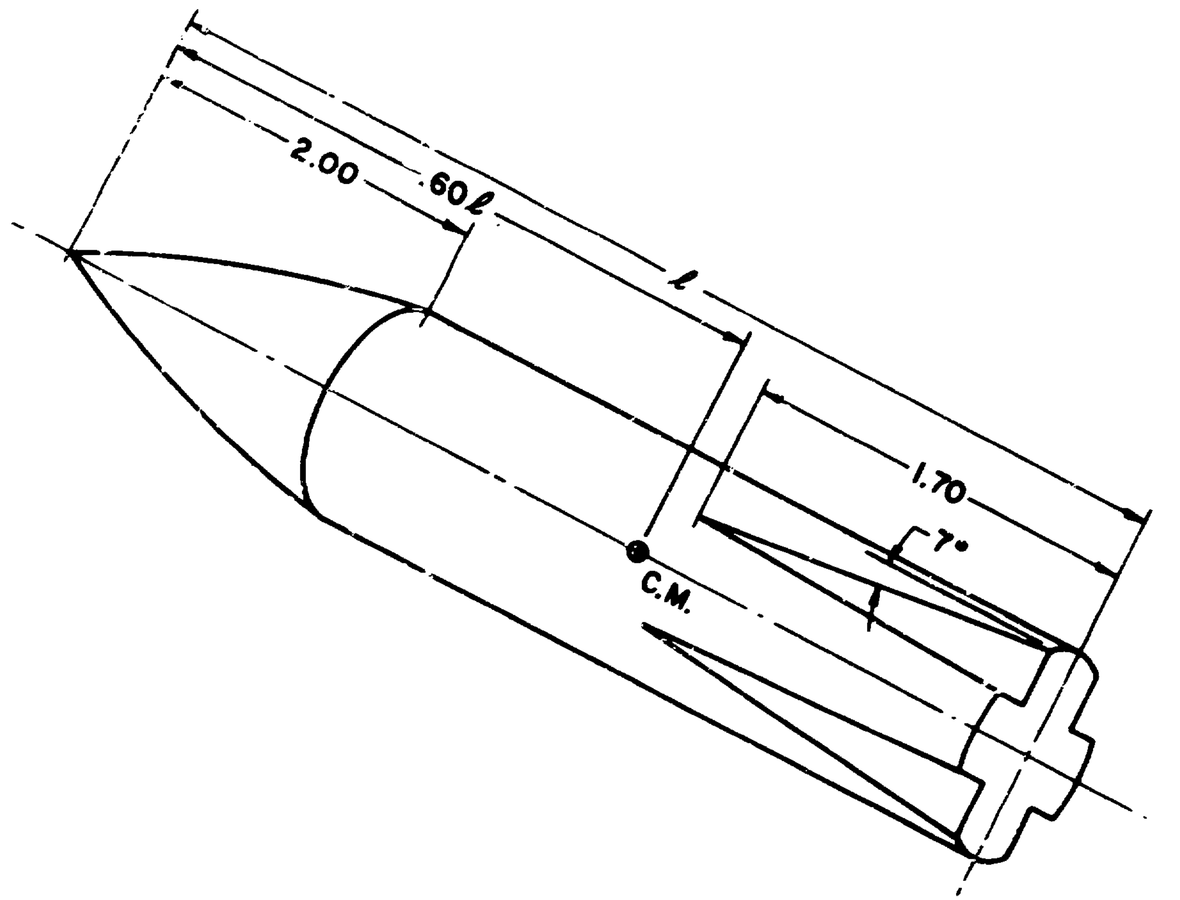

Figure 5. The Wind Tunnel Model of the Cruciform Wedge Boattail, Dimensions in Calibers, ℓ = 5, 6, or 7 Calibers

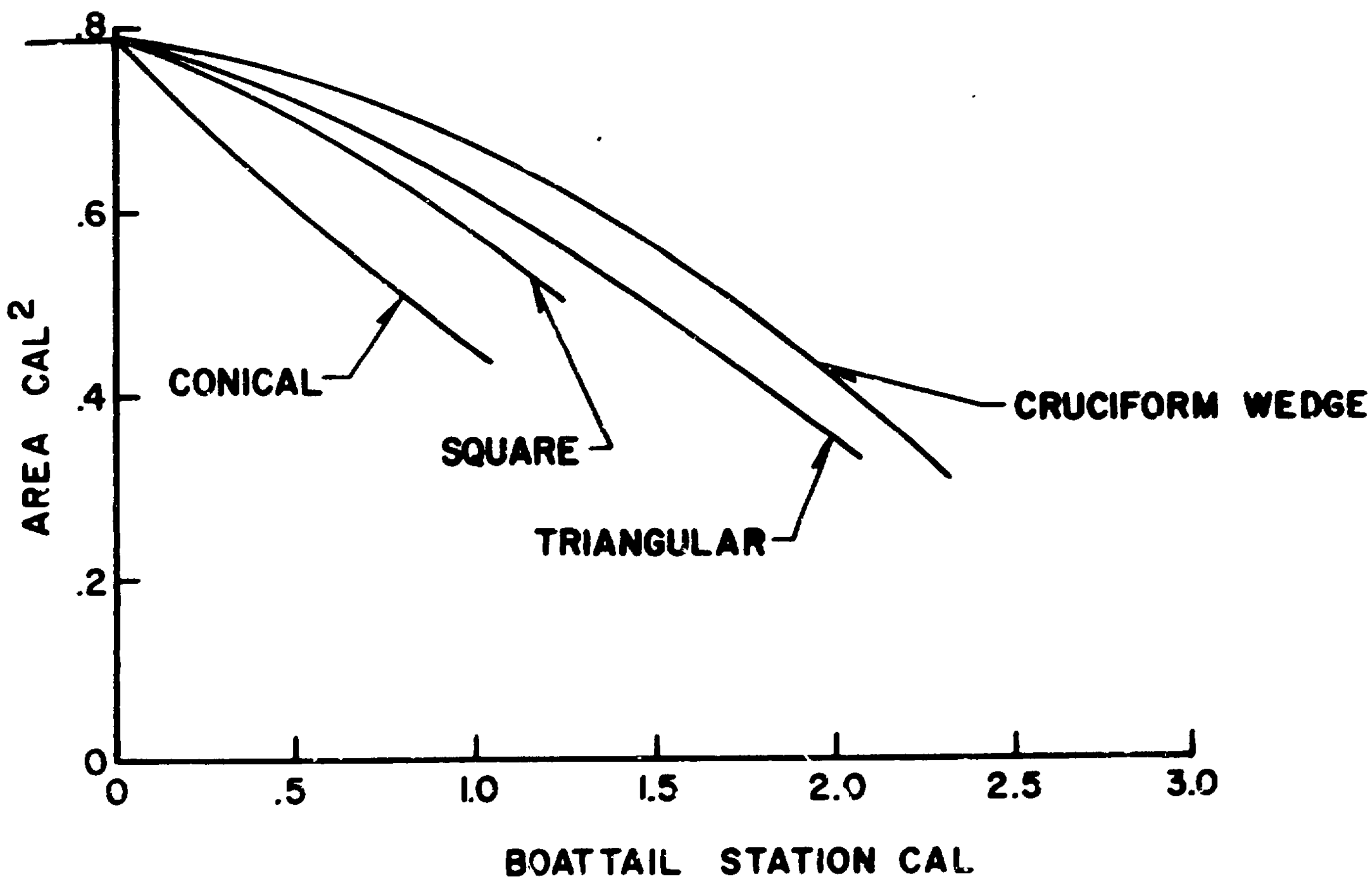

Figure 6. Cross Sectional Areas of 7° Boattails

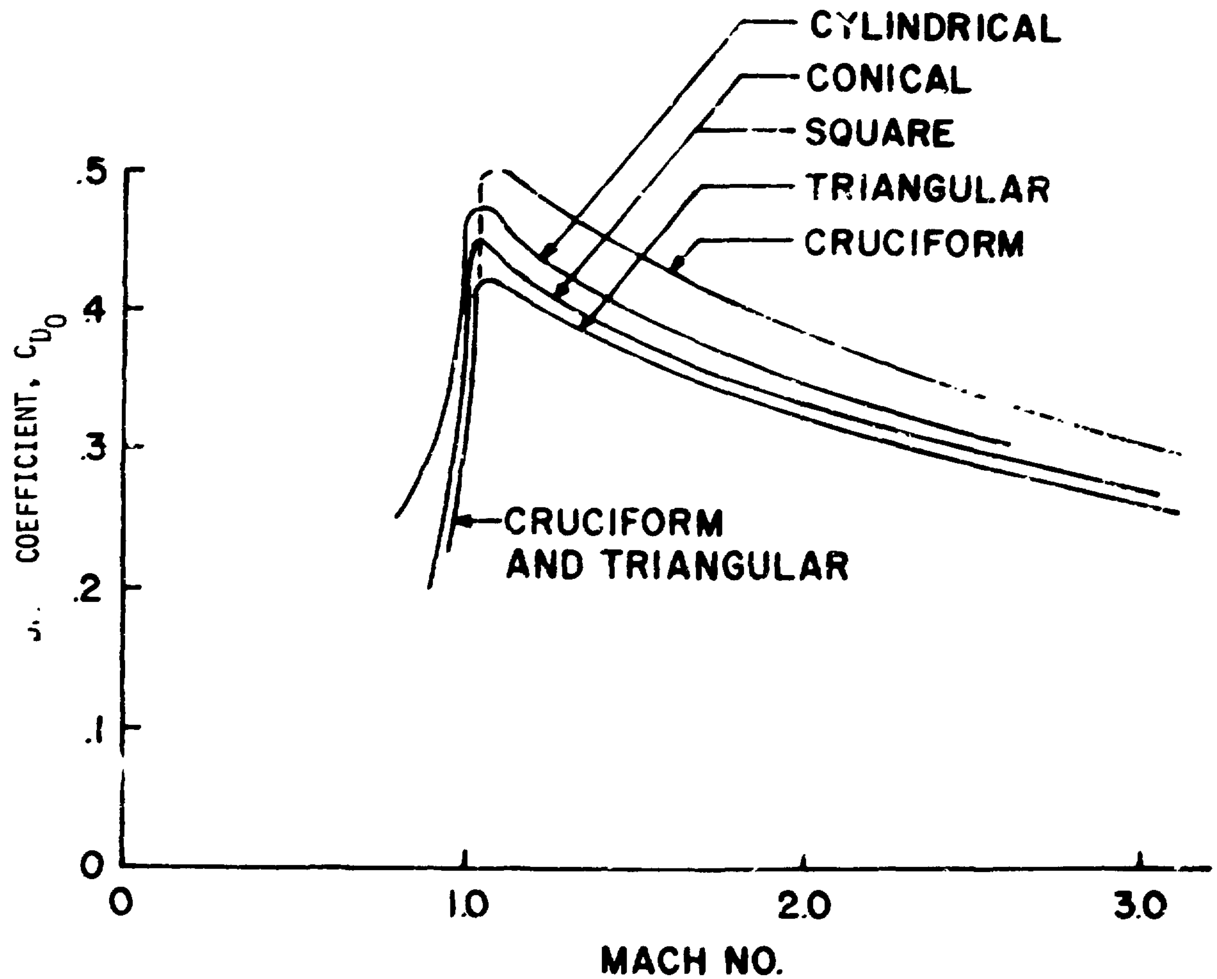

Figure 7. The Zero Yaw Drag of the Improved Boattails

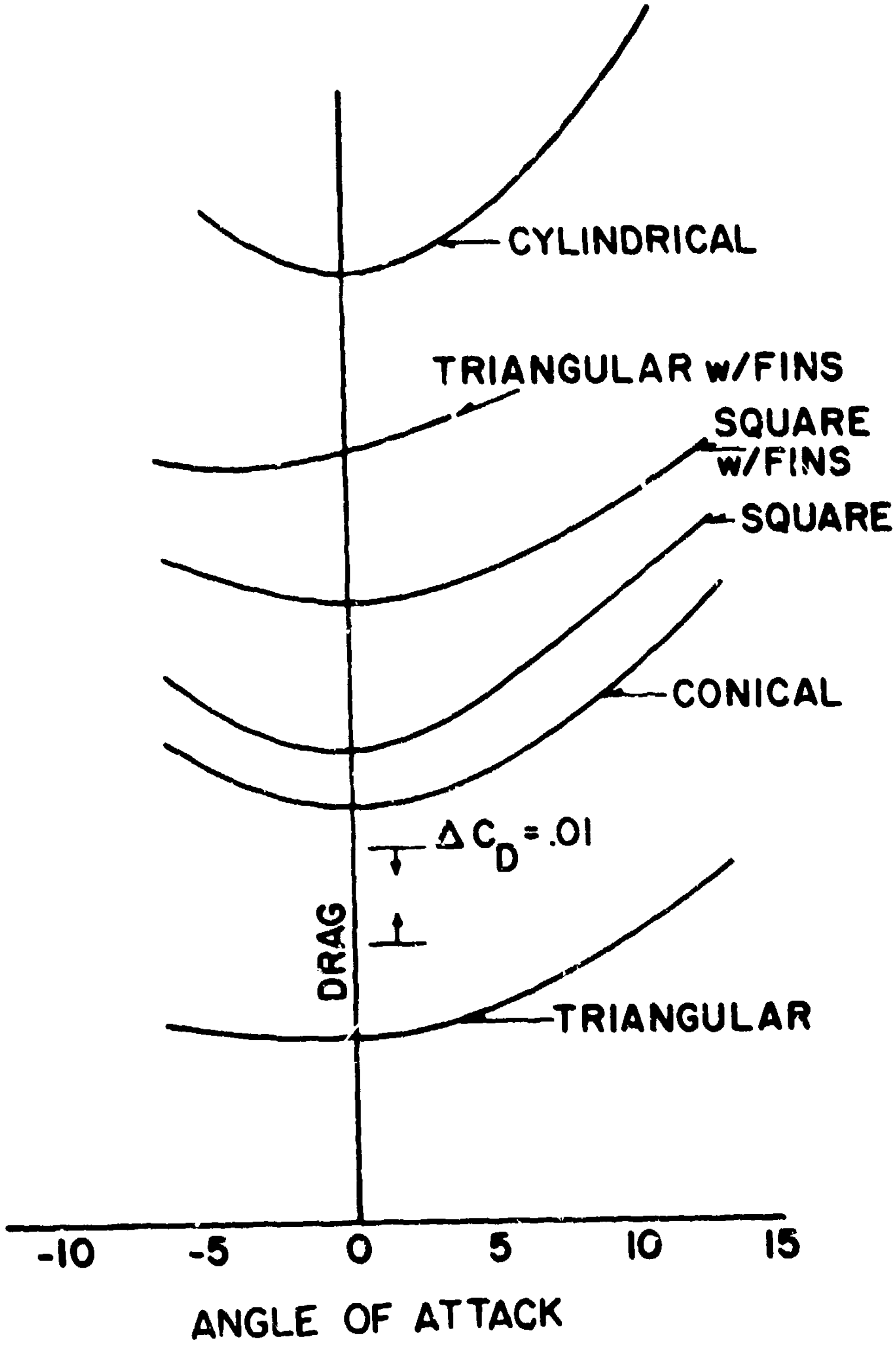

Figure 8. The Drag Polars for Various Boattails at M = .5

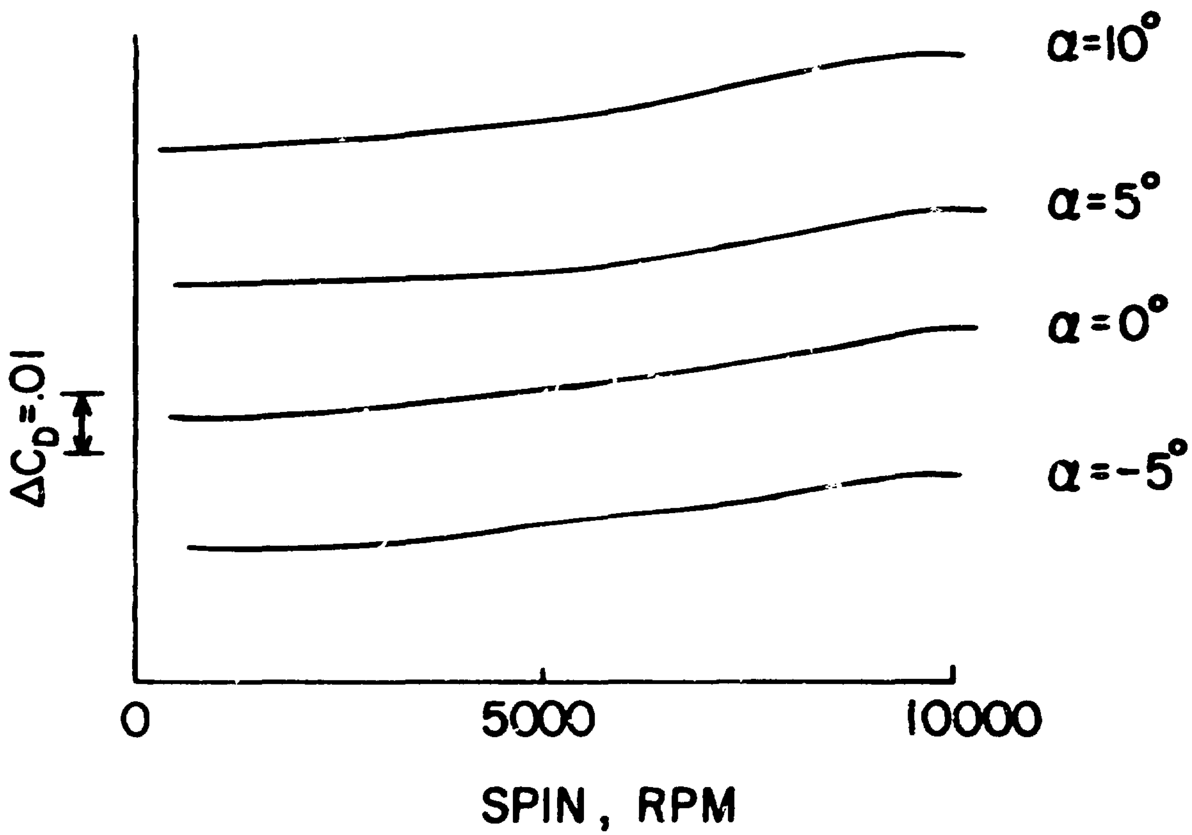

Figure 9. The Drag Variation Due to Spin on the Straight Square Boattail at M = .9

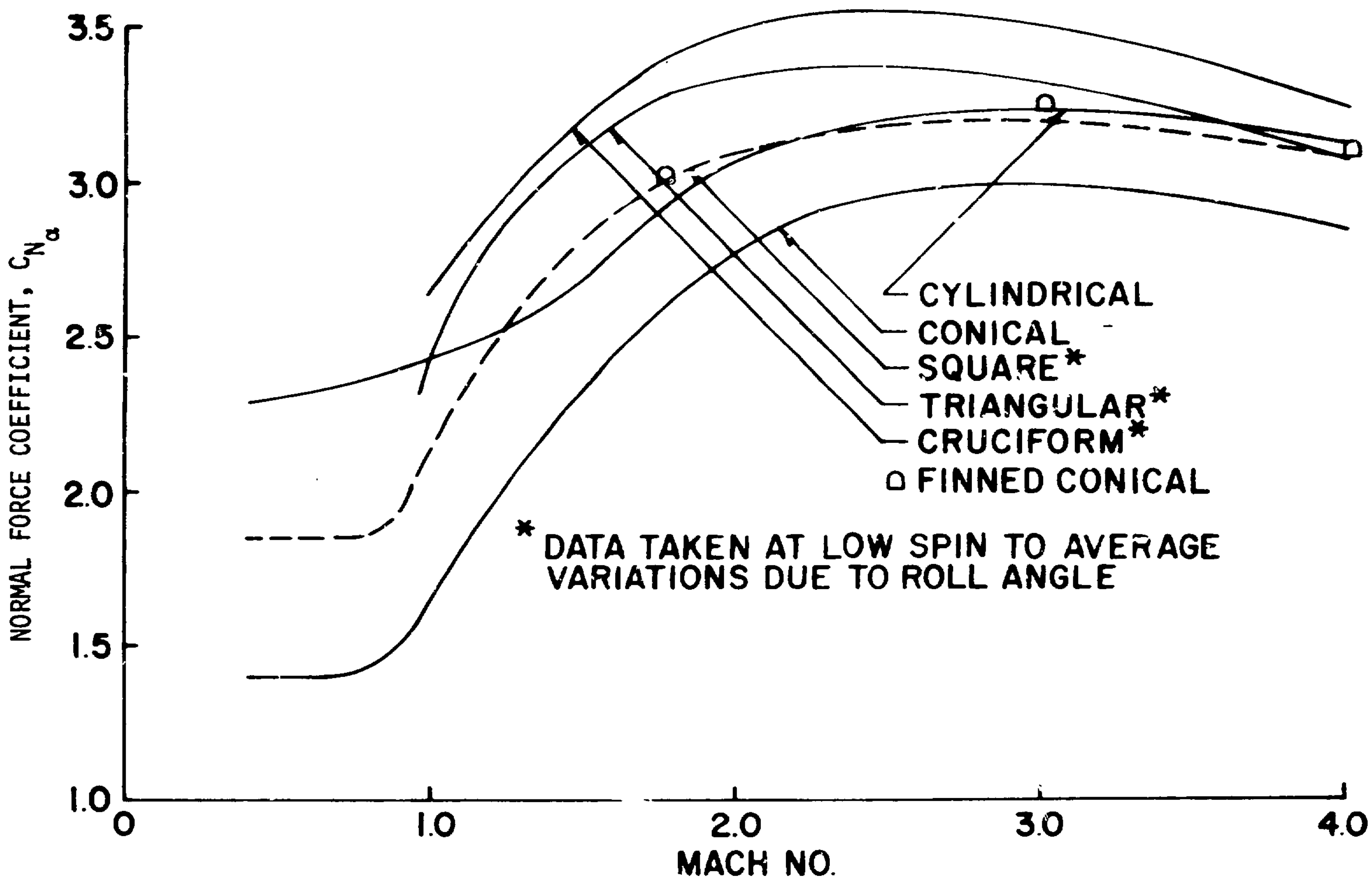

Figure 10. The Normal Force on the Improved Boattail Configurations

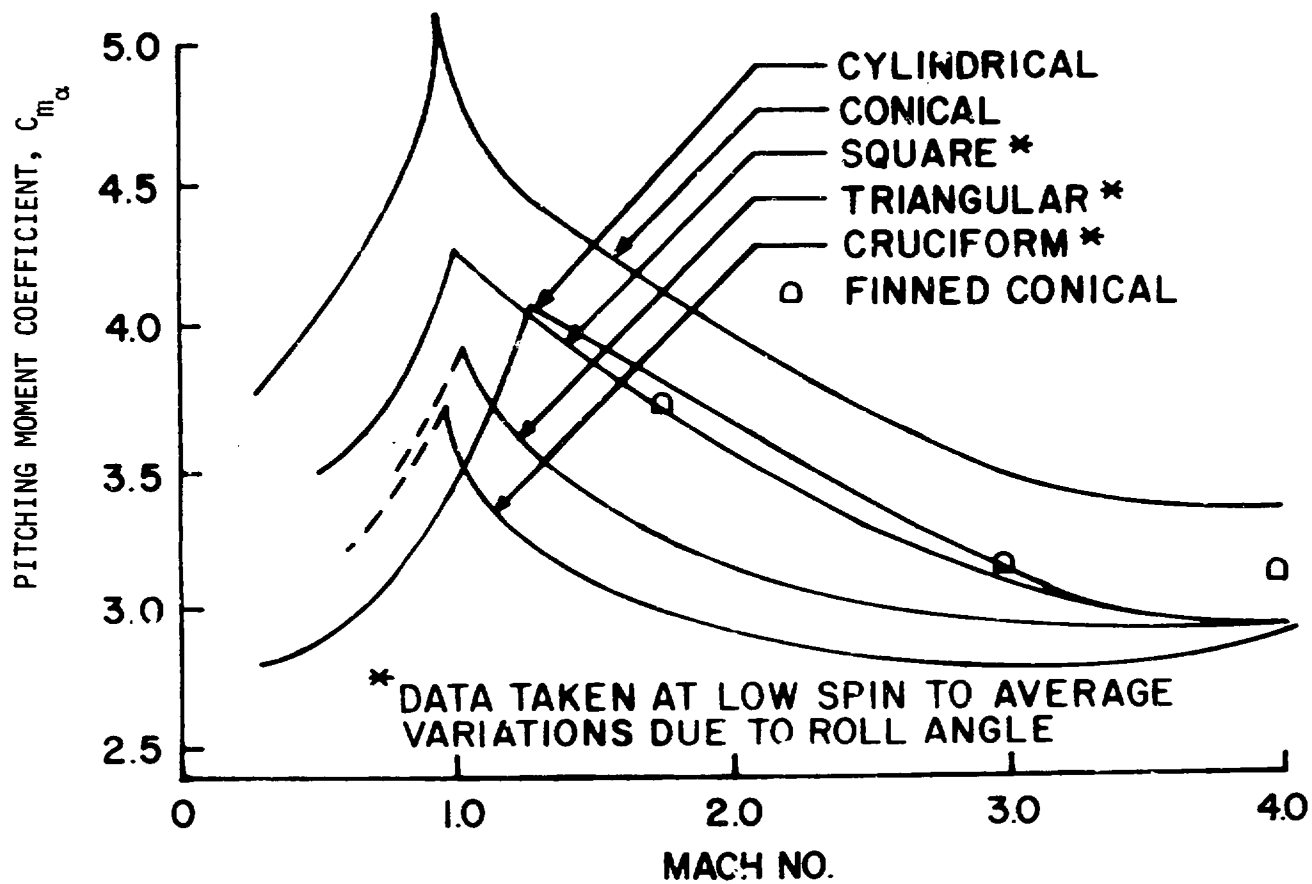

Figure 11. The Pitching Moment on the Improved Boattails

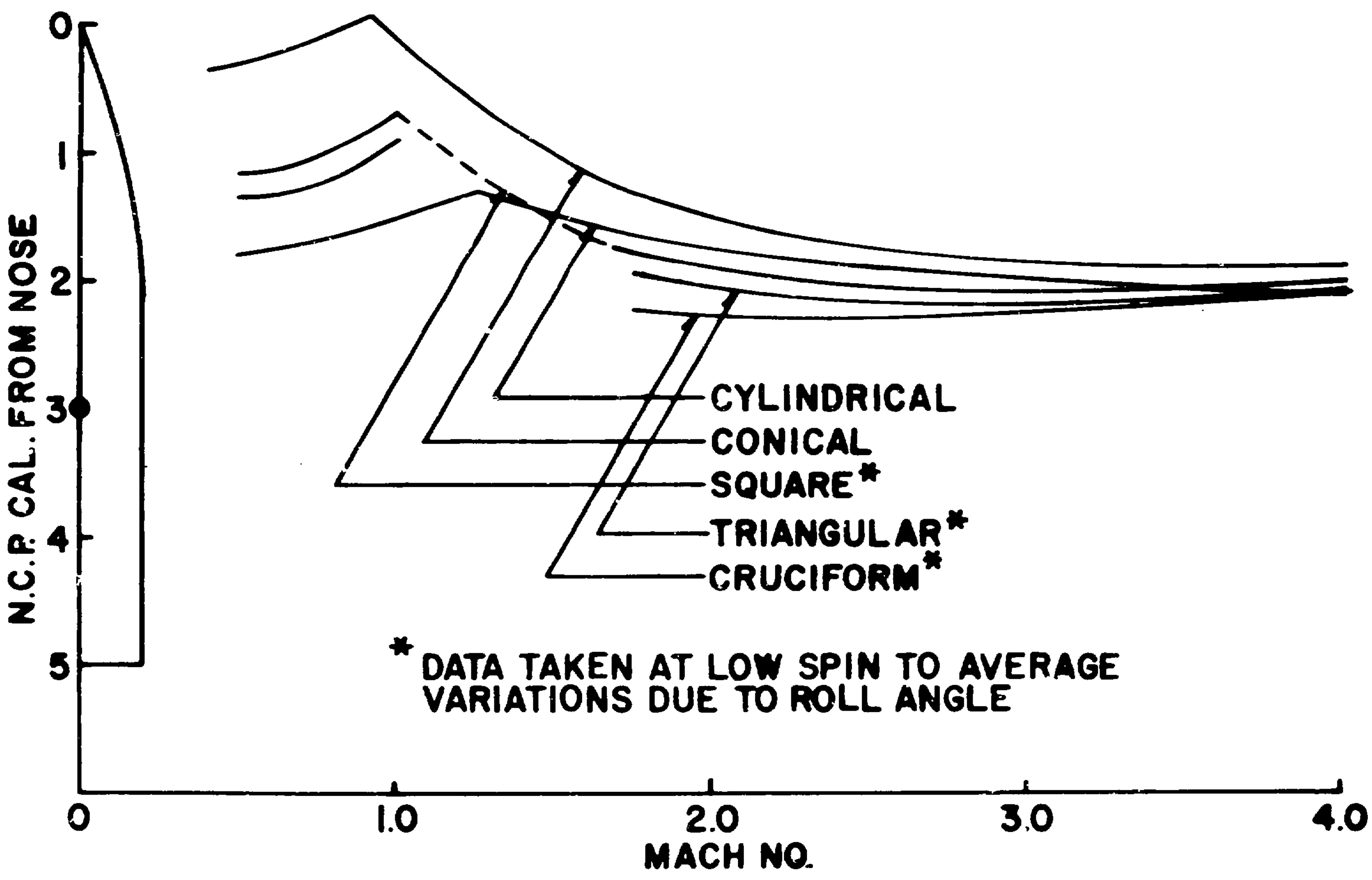

Figure 12. The Normal Force Center of Pressure on the Improved Boattails

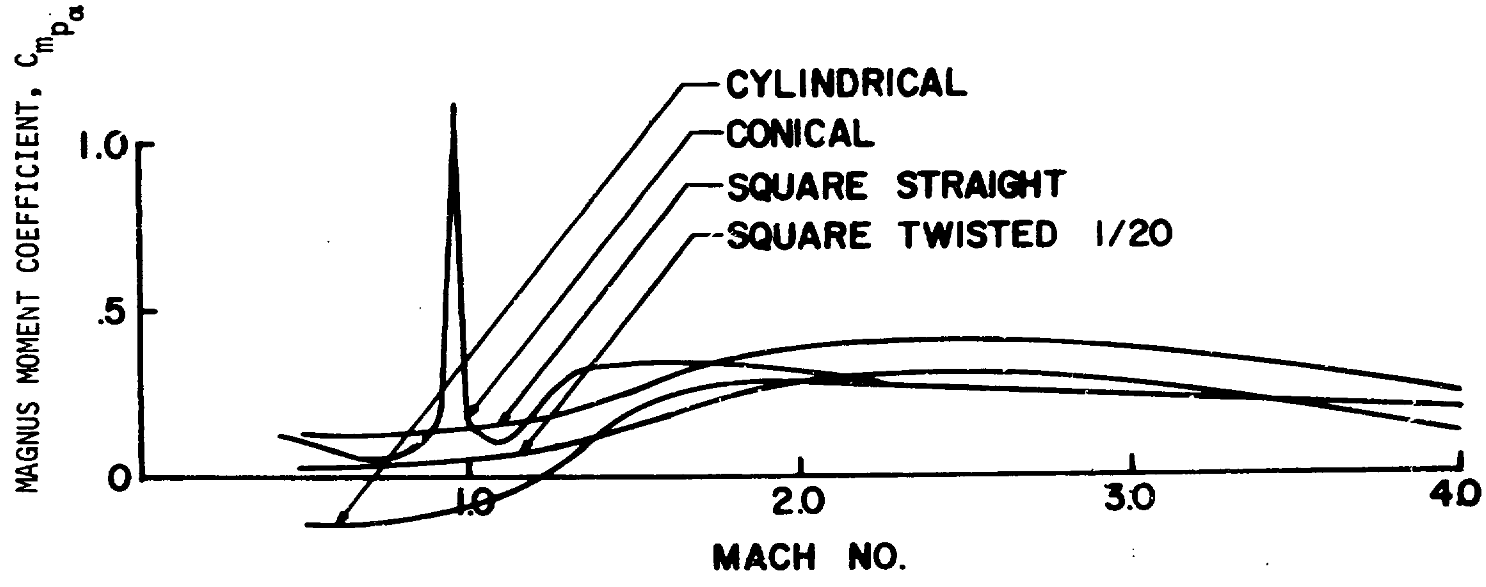

Figure 13. The Magnus Moment on the Improved Boattails at Low Angles of Attack

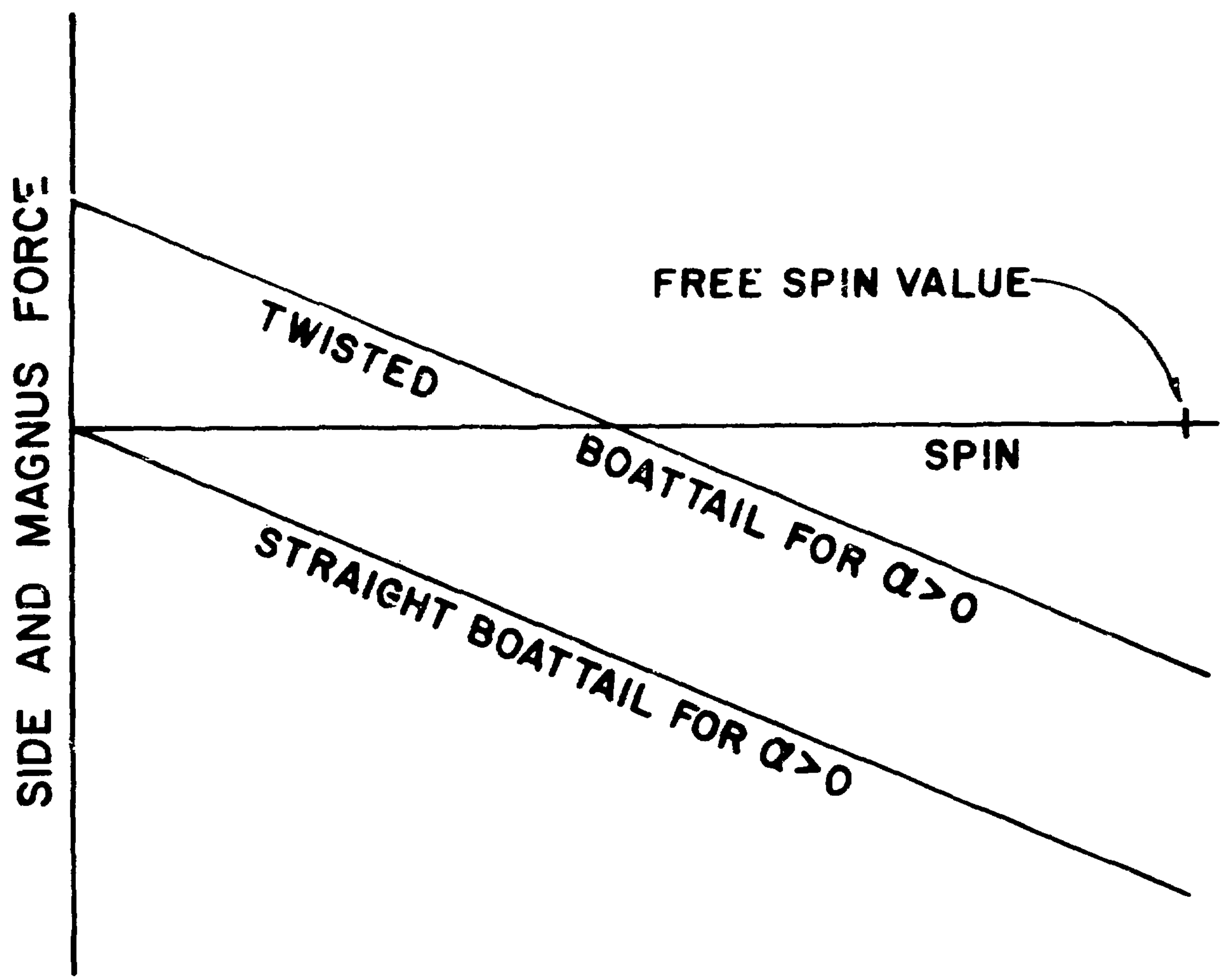

Figure 14. The Side and Magnus Forces on the Straight and Twisted Boattails

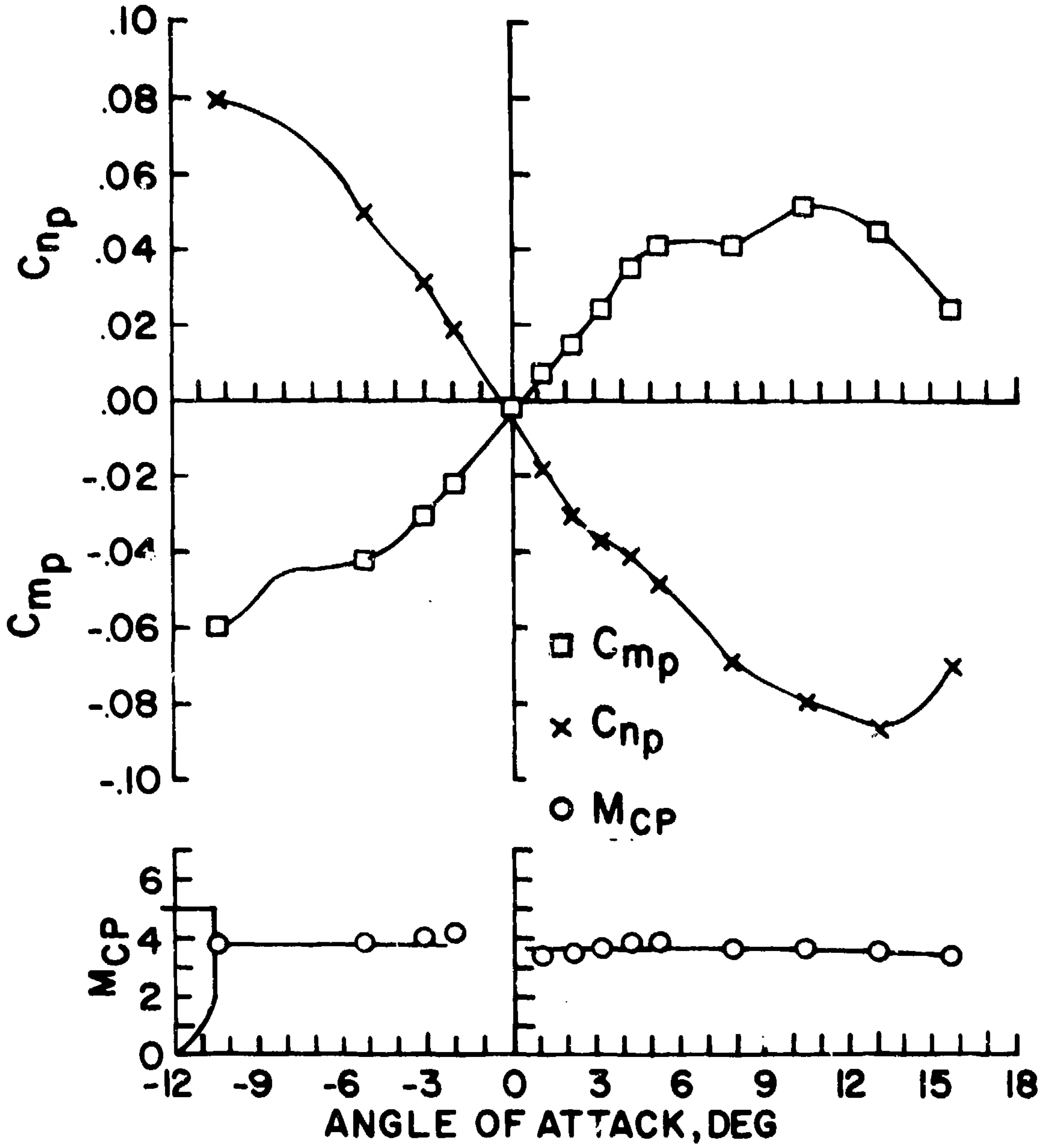

Figure 15. The Magnus Characteristics of the Triangular Boattail at M = 2.5, pd/V = .27, R_{dia} = .94 x 10^6

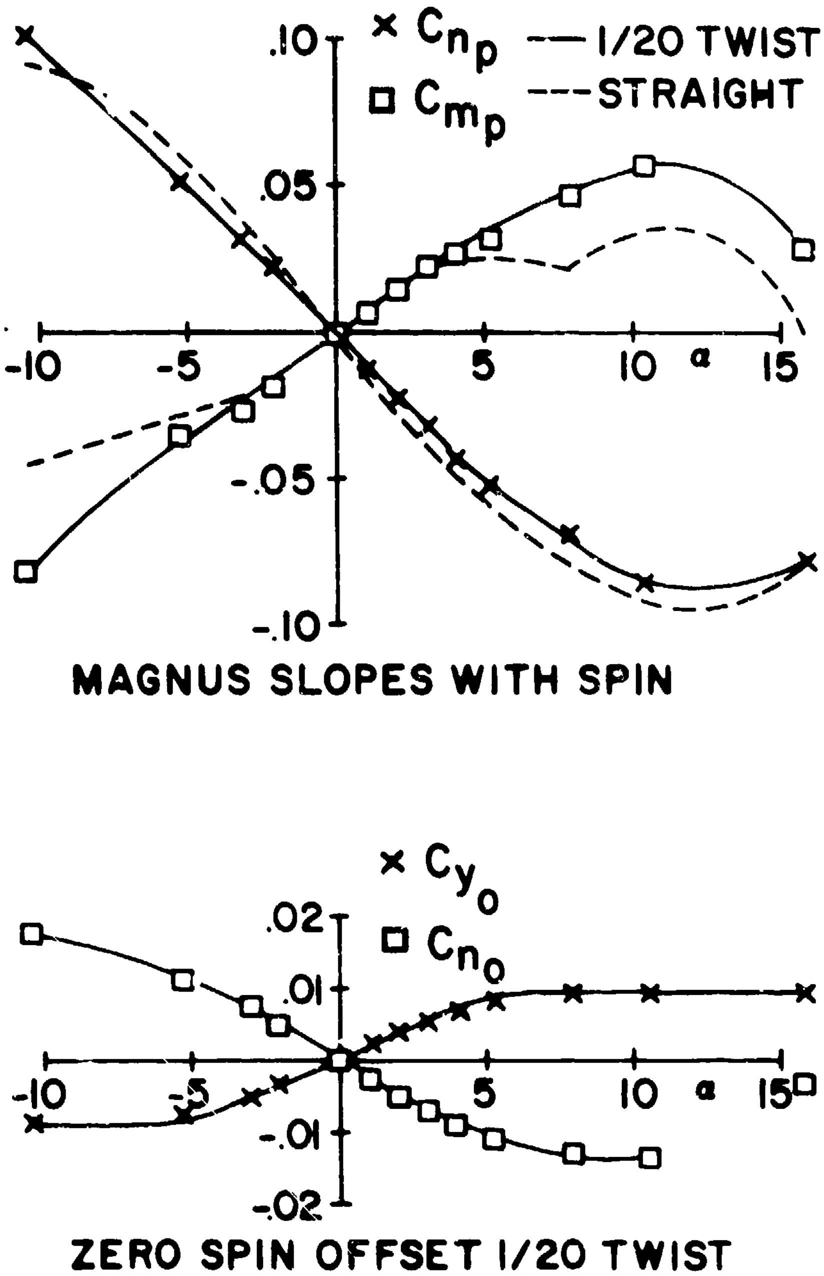

Figure 16. The Magnus Offsets and Slopes on the Triangular Boattail at M = 2.5, R_{dia} = 950,000

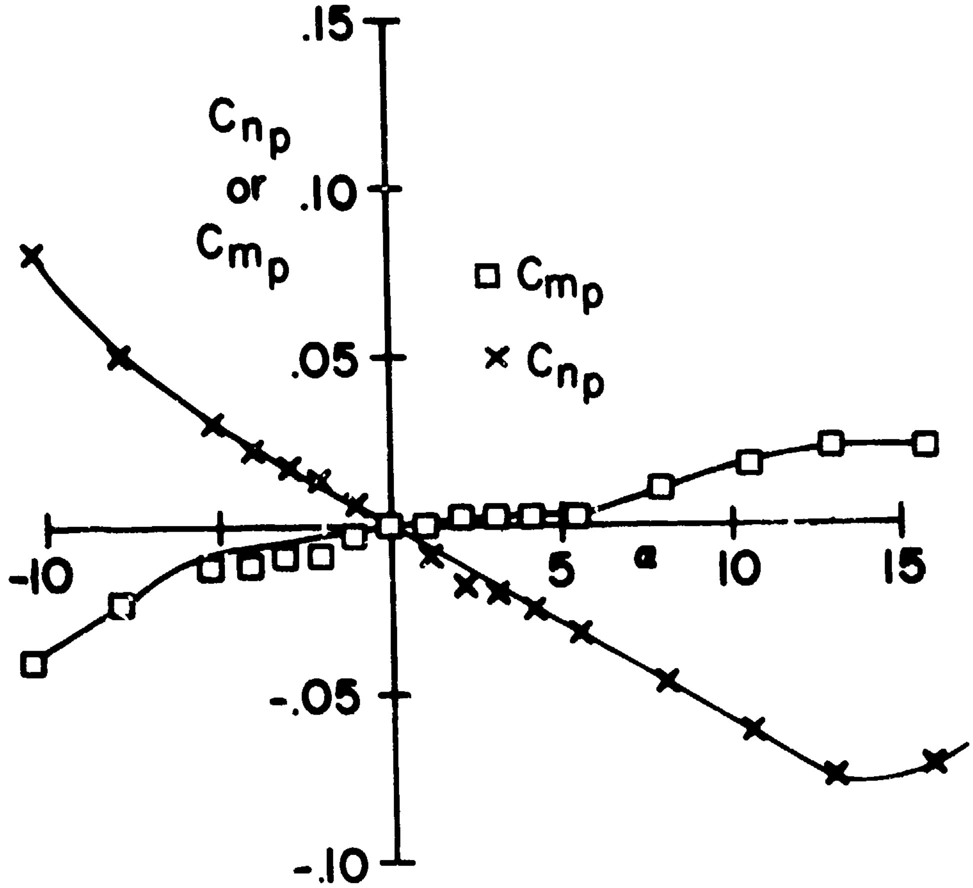

Figure 17. The Magnus Characteristics of the Triangular Boattail With a 1/20 Twist at a Spin Rate (pd/V = .412), M = 2.5, R_{dia} = 950,000

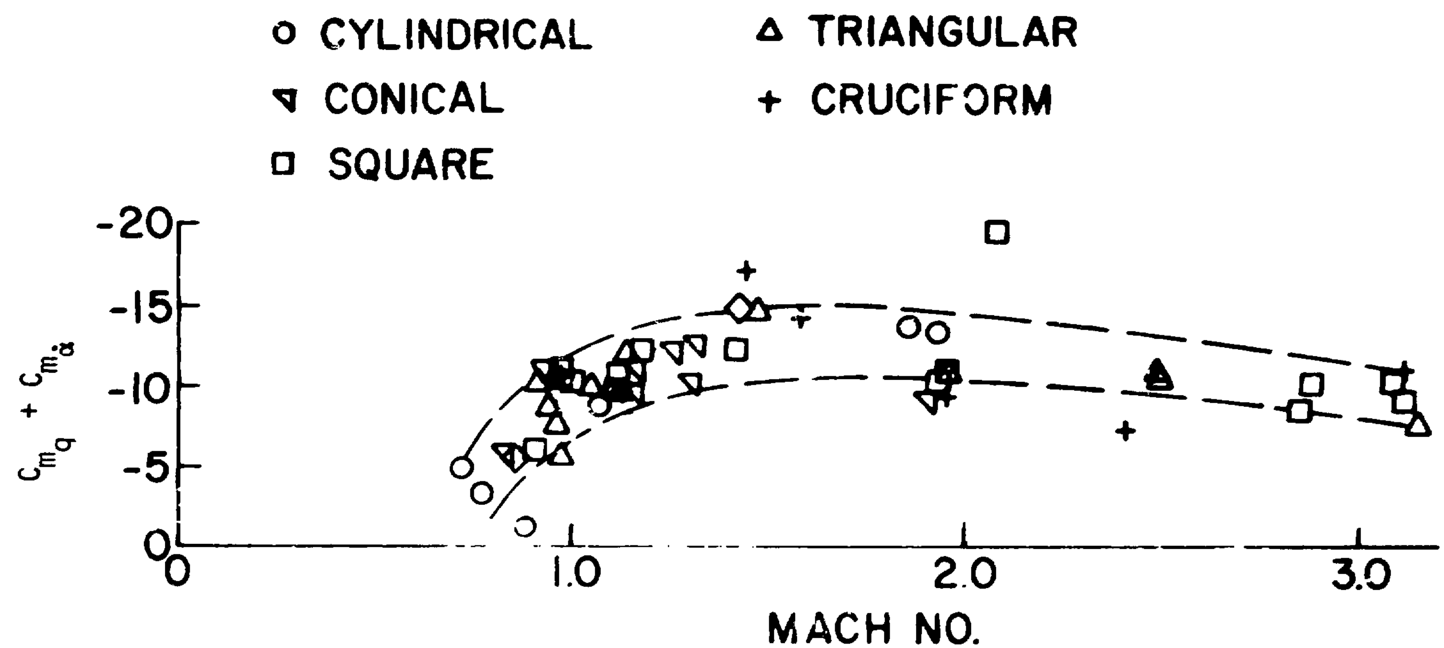

Figure 18. The Damping in Pitch of Various Boattails

APPENDIX A

Aerodynamic Data on the Improved Projectile Boattails

Page

FREE FLIGHT RANGE DATA

5 cal. A-N Spinner Rocket with 7° Straight Square Boattail

M Mid-Range Value	R_{dia} X 10^{-6}	C_{D_o}	C_{N_α}	C_{m_α}	$C_{N_{p_\alpha}}$	$C_{m_{p_\alpha}}$	C_{ℓ_p}	C_{ℓ_δ}	$C_{m_q} + C_{m_\alpha}$
.89	.40	.188	1.94	3.81	- .65	.26	-.055	0	- 6.1
1.12	.51	.447	2.51	3.75	-1.13	-.30	Average ↓	↓	-10.0
1.42	.64	.405	2.84	3.62	- .67	-.16			-12.3
1.96	.89	.359	3.16	3.48	- .46	+.37			-11.9
2.07	.94	.351		3.56		+.92			-19.7
2.85	1.28	.277	3.53	3.13	- .55	+.36			- 8.5
		$C_{D_{\alpha^2}} = 6$							

5 cal. A-N Spinner Rocket with 7° Twisted Square Boattail

M Mid-Range Value	R_{dia} X 10^{-6}	C_{D_o}	C_{N_α}	C_{m_α}	$C_{N_{p_\alpha}}$	$C_{m_{p_\alpha}}$	C_{ℓ_p}	C_{ℓ_δ}	$C_{m_q} + C_{m_\alpha}$
1.02	.46	.395		4.26		-.17	-.055	+.037	-10.3
1.03	.46	.412		4.05			Av. from Above ↓	Average ↓	
1.15	.52	.418	2.17	4.05		-.16			-10.8
1.19	.54	.422	2.40	3.99	- .30	+.07			-12.6
1.93	.88	.343	3.09	3.49	- .53	+.05			-10.6
1.94	.88	.341	3.19	3.54	- .33	+.14			-11.8
2.88	1.32	.275	3.13	3.14	.04	+.27			-10.2
3.10	1.38	.266	3.20	3.10	- .82	+.10			-10.5
3.12	1.39	.247		2.99	- .60	+.20			- 9.2
		$C_{D_{\alpha^2}} = 6$							

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FREE FLIGHT RANGE DATA (continued)

5 cal. A-N Spinner Rocket with 7° Straight Triangular Boattail

M Mid-Range Value	$R_{dia} \times 10^{-6}$	C_{D_o}	C_{N_α}	C_{m_α}	$C_{N_{p_\alpha}}$	$C_{m_{p_\alpha}}$	C_{ℓ_p}	C_{ℓ_δ}	$C_{m_q} + C_{m_\alpha}$
.93	.42	.227	2.28	3.79	+ .01	-.19	-.098	0	-11.0
.94	.42	.192	2.53	3.80	+ .57	+.09	Average ↓	↓	-10.3
.96	.43	.208	2.56	4.11	- .18	+.17			- 8.9
1.04	.46	.398	2.75	3.74	- .11	+.09			-10.0
1.16	.52	.411	2.63	3.50	- .24	-.07			-12.4
1.49	.67	.380	3.30	3.48	-1.40	-.08			-15.0
1.71	.76	.357	3.00	3.33	- .68	-.03			-10.4

5 cal. A-N Spinner Rocket with 7° Twisted Triangular Boattail

M Mid-Range Value	$R_{dia} \times 10^{-6}$	C_{D_o}	C_{N_α}	C_{m_α}	$C_{N_{p_\alpha}}$	$C_{m_{p_\alpha}}$	C_{ℓ_p}	C_{ℓ_δ}	$C_{m_q} + C_{m_\alpha}$
.973	.44	.251	1.91	4.28	-1.35	-1.12	-.098	+.084	
.973	.44	.239	2.05	4.28	- .67	- .78	Av. from Above ↓	Average ↓	
.984		.302	2.10	4.35	+ .38	- .14			- 5.8
1.00	.45	.331		4.29	1.30	+ .15			- 2.4
1.127	.51	.397	2.36	4.02	- .92	- .43			- 9.9
1.96	.89	.318	3.31	3.31	- .41	- .27			-10.8
1.97	.89	.320	3.34	3.26	- .23	- .16			-10.2
2.47	1.13	.280	3.36	2.84	- .16	- .09			-11.9
3.15	1.41	.256	3.17	2.95	.12	- .03			- 7.8

FREE FLIGHT RANGE DATA (continued)

5 cal. A-N Spinner Rocket with 7° Straight Cruciform Boattail

M Mid-Range Value	$R_{dia} \times 10^{-6}$	C_{D_o}	C_{N_α}	C_{m_α}	$C_{N_{p_\alpha}}$	$C_{m_{p_\alpha}}$	C_{ℓ_p}	C_{ℓ_δ}	$C_{m_q} + C_{m_\alpha}$
1.44	.65	.458	2.23	2.40	- .75	+.44	.073	0	-17.1
1.59	.71	.441	3.32	3.11	- .34	.26	Av.		-14.3
2.42		.342	3.44	2.74	-1.12	.29			- 7.5

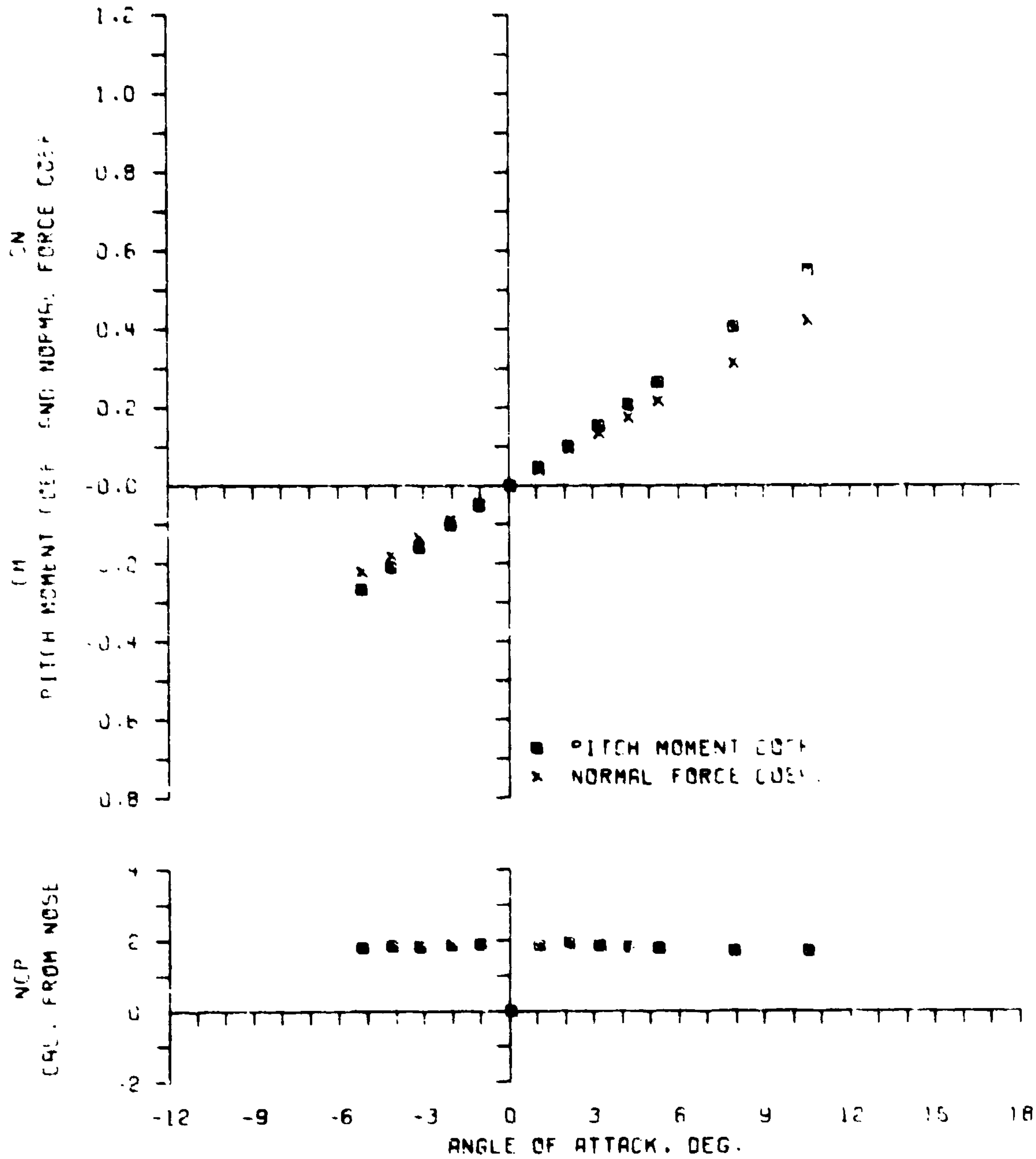
5 cal. A-N Spinner Rocket with 7° Twisted Cruciform Boattail

M Mid-Range Value	$R_{dia} \times 10^{-6}$	C_{D_o}	C_{N_α}	C_{m_α}	$C_{N_{p_\alpha}}$	$C_{m_{p_\alpha}}$	C_{ℓ_p}	C_{ℓ_δ}	$C_{m_q} + C_{m_\alpha}$
.965	.44	.265	2.60	3.68	- .59	-.29	-.073	+.063	- 9.7
1.138	.51	.487	3.02	3.24	- .03	-.37	Av. from Above		- 9.7
1.941		.387	3.50	2.98	- .88	-.10			- 9.6
3.103	1.39	.281		2.75	+ .33	-.06			-11.4

All flights are low angle of attack, Maximum α = 5°.

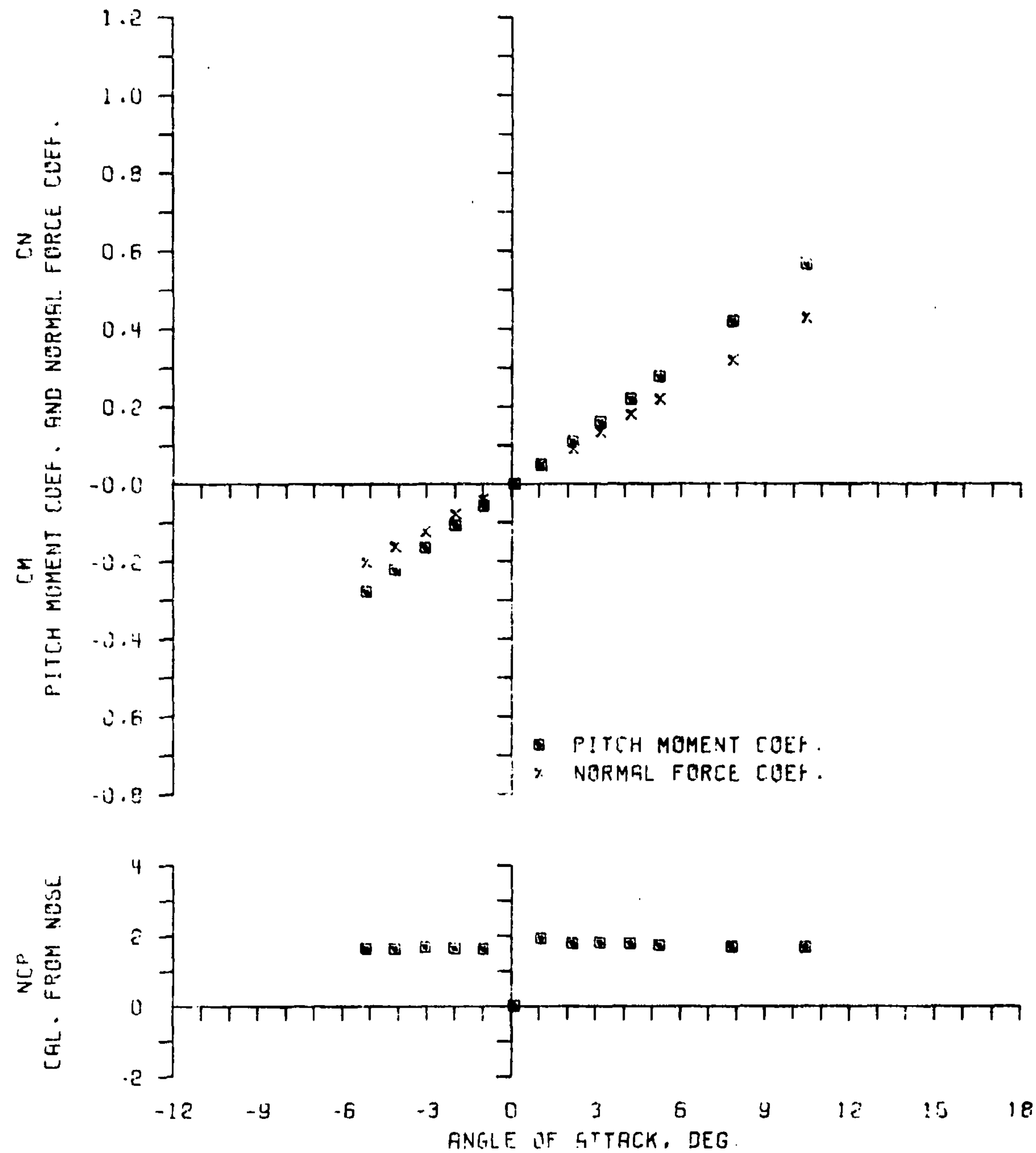
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL

MACH 0.50 R(DIA) 0.99 X 10^6



CONFIG. 5 00 RUN= 55.

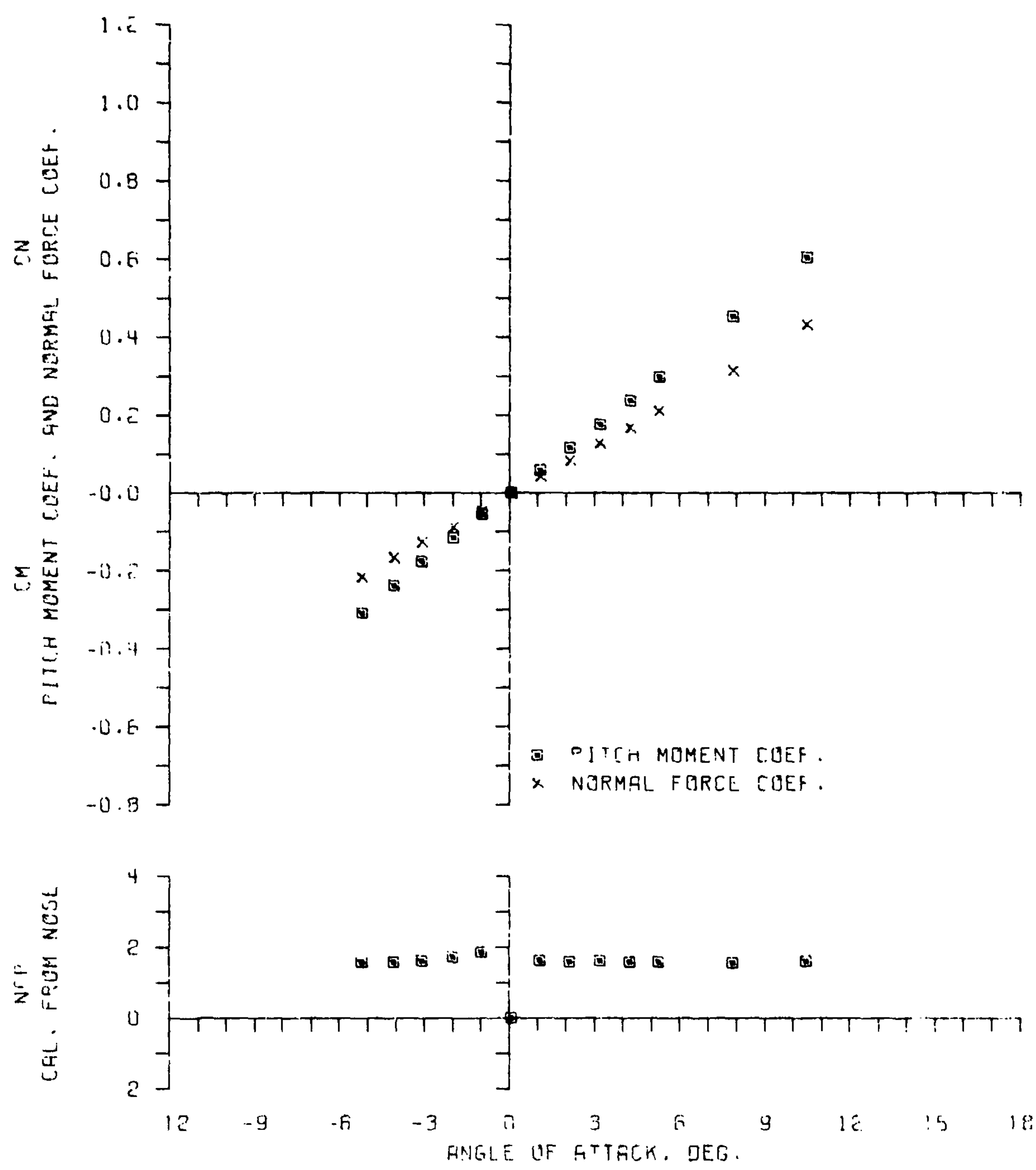
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 0.70 R(DIA) 0.57 X 10^6



FIG= 5.00 RUN= 54.

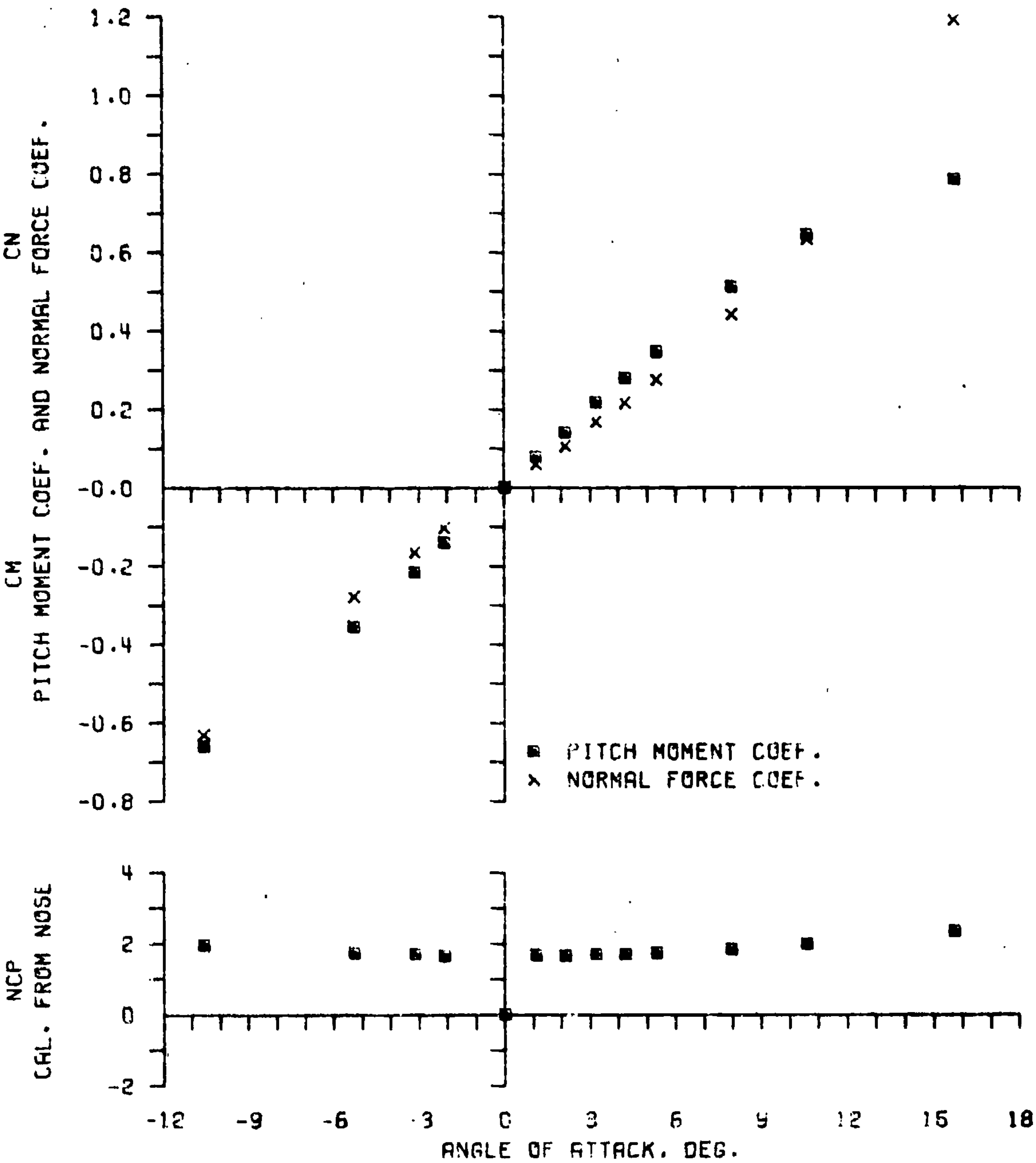
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL

MACH 0.90 R(DIA) 0.48 X 10^6



CONFIG. 5.00 RUN= 53.

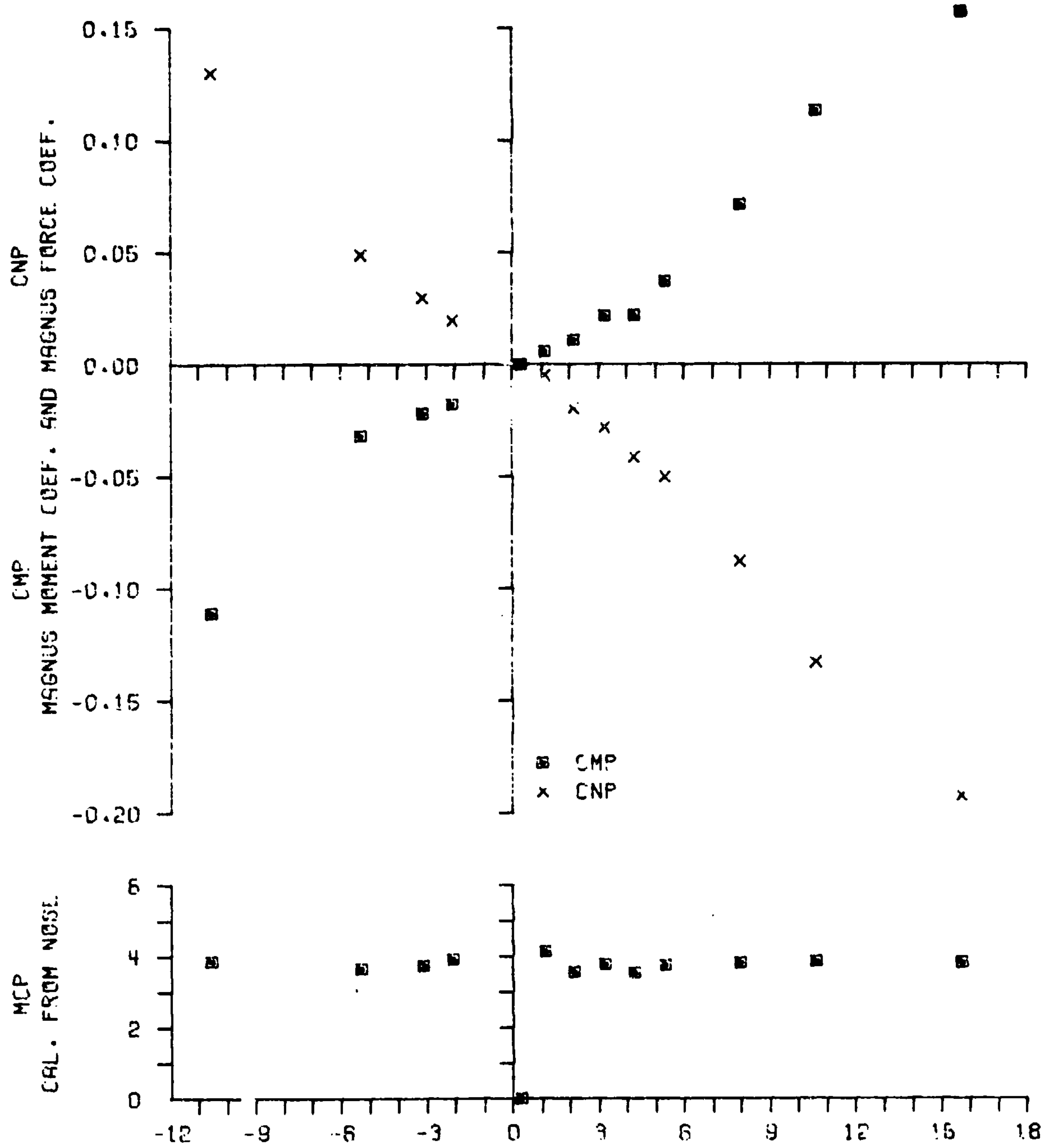
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 1.75 R(DIA) 0.91 X 10^6



CONFIG= 5.00 RUN= 7.

42

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 1.75 PD/V 0.37 R(DIA) 0.91 X 10^6



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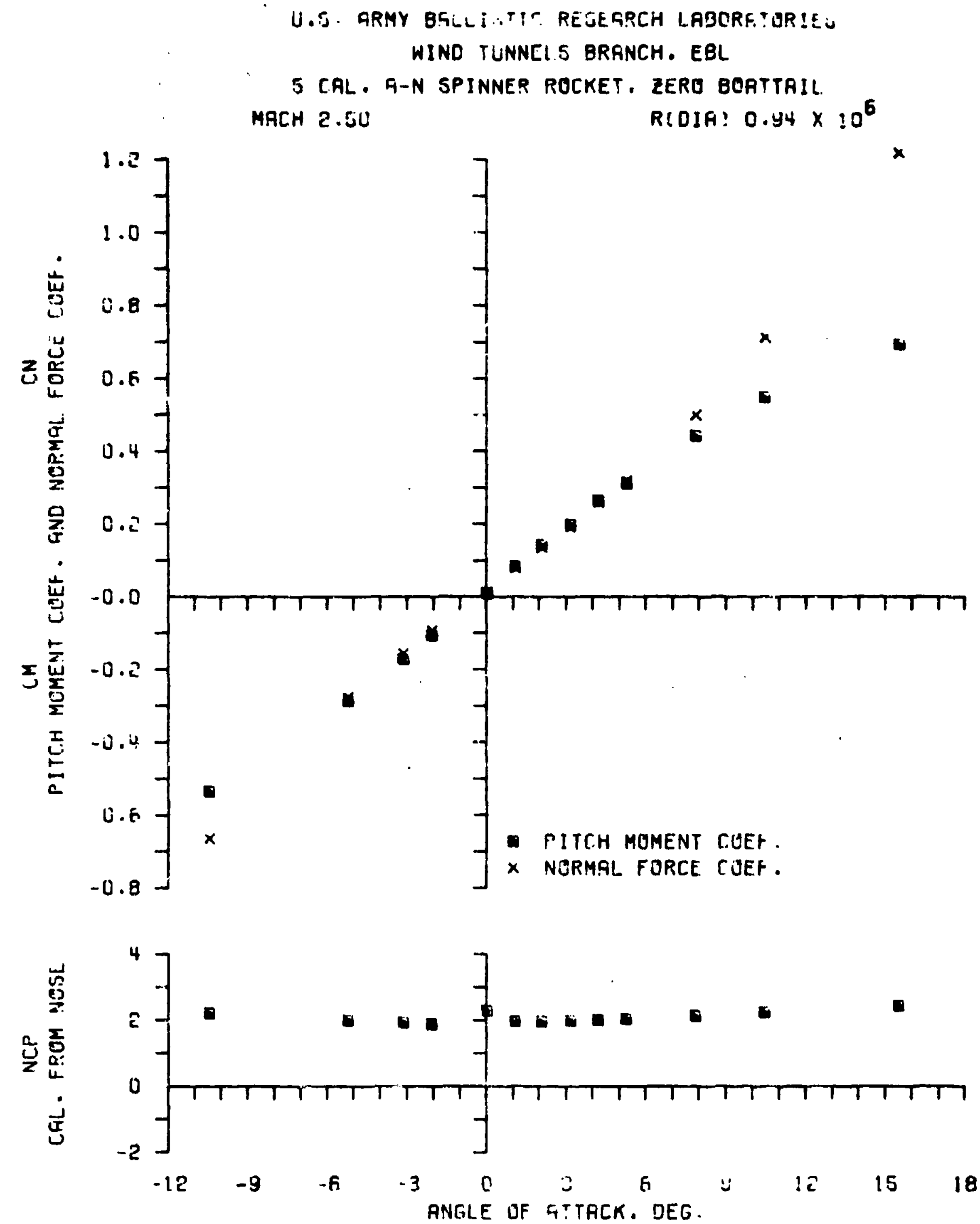
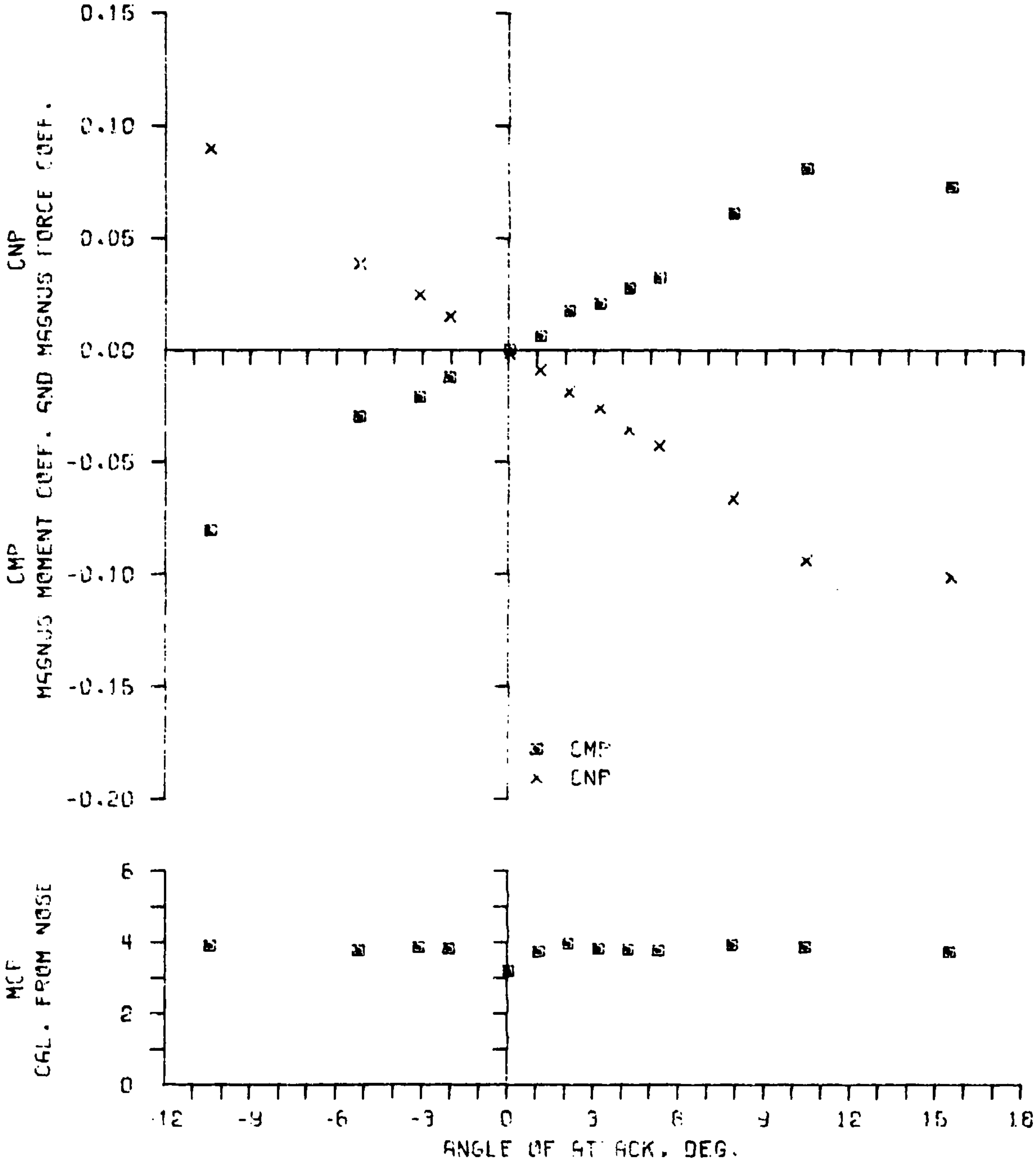


CONFIG= 5.00 RUN= 8.

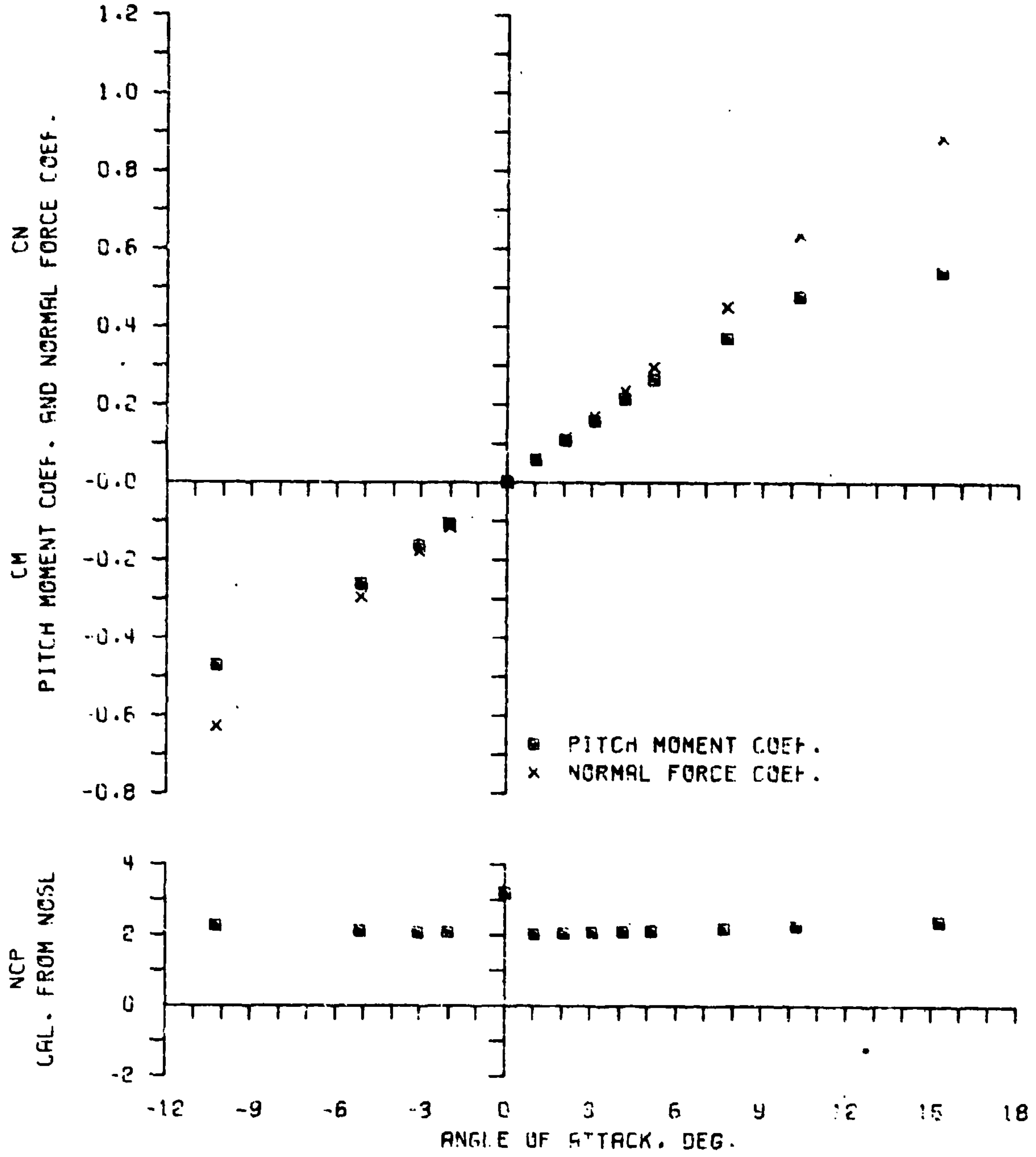
44

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 2.50   PD/V 0.31   R(DIA) 0.94 X 10^6



CONFIG= 5.00 RUN= 8.

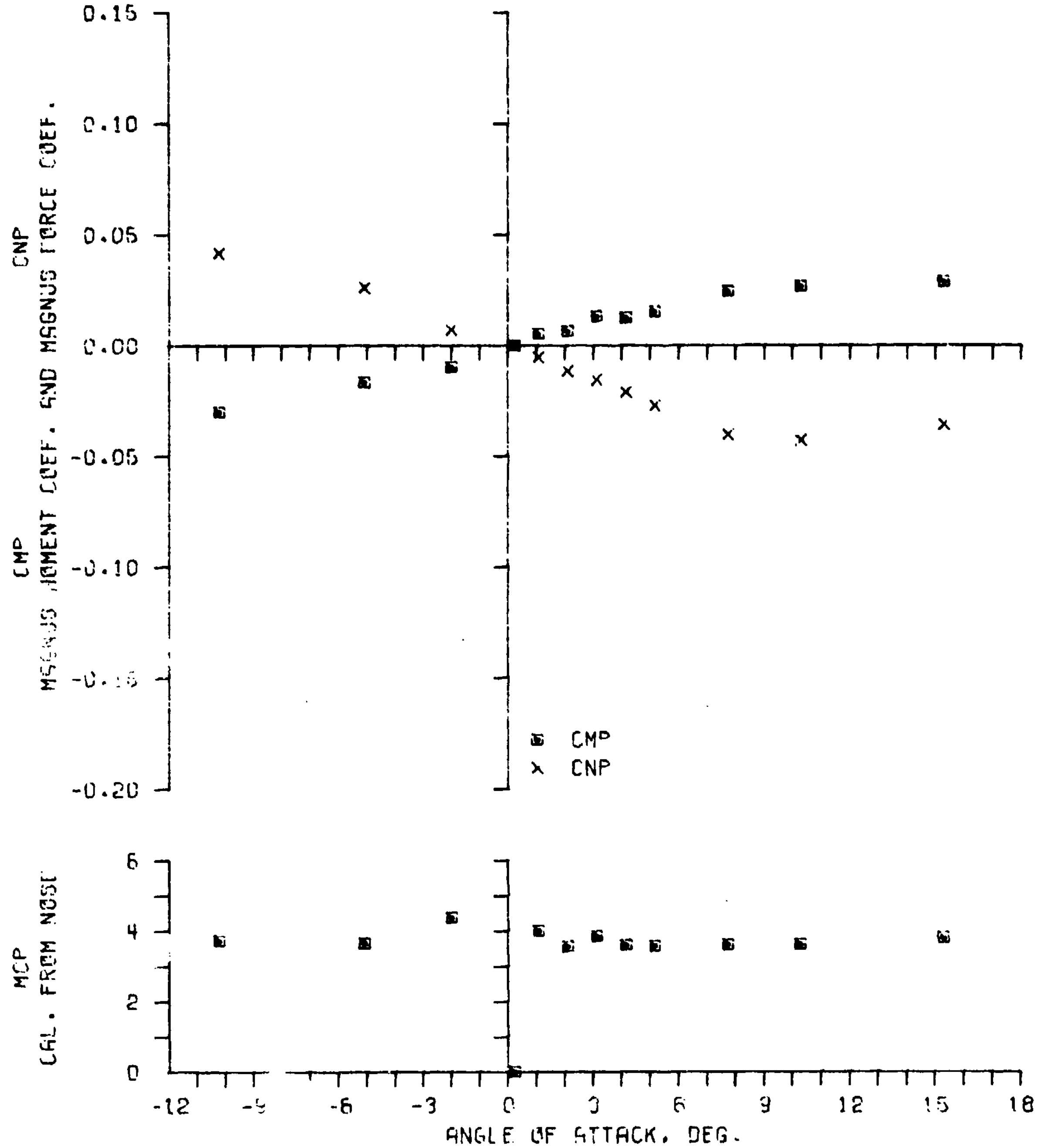
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 4.00 R(DIA) 1.00 X 10^6



CONFIG= 5.00 RUN= 9.

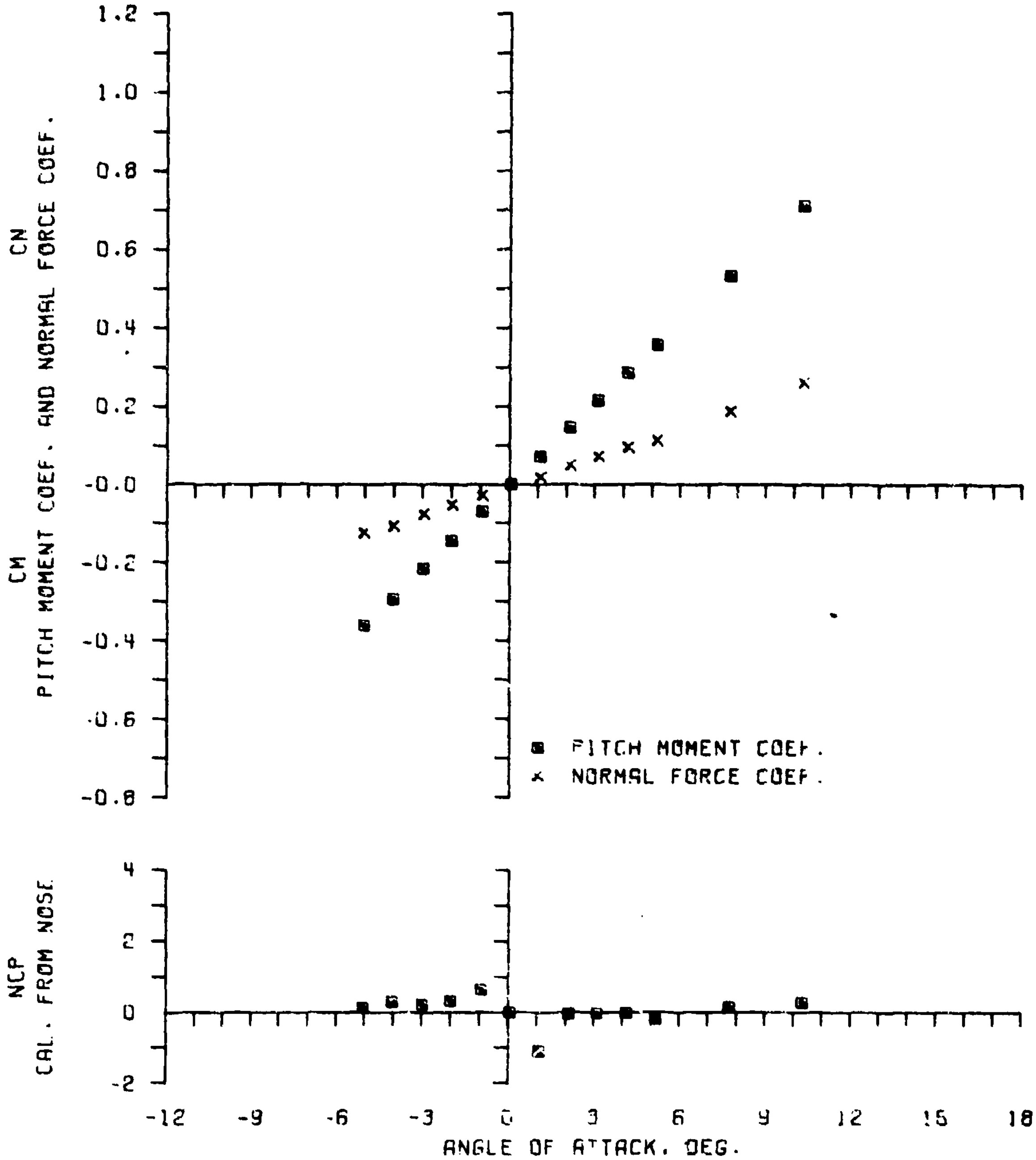
46

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ZERO BOATTAIL
MACH 4.00 PD/V 0.26 R(DIA) 1.00 X 10^6



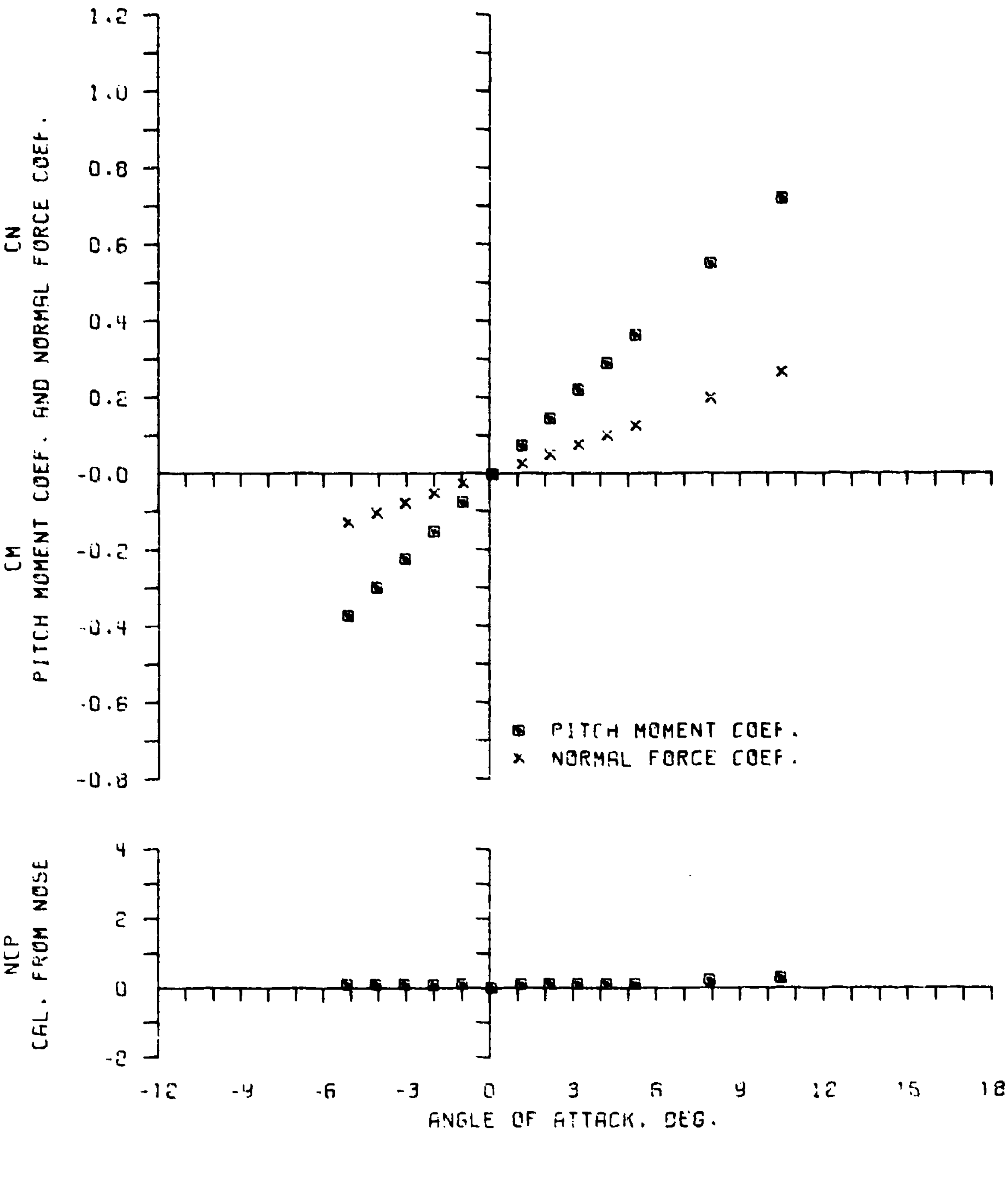
CONFIG= 5.00 RUN= 9

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.50 R(DIA) 0.55×10^6



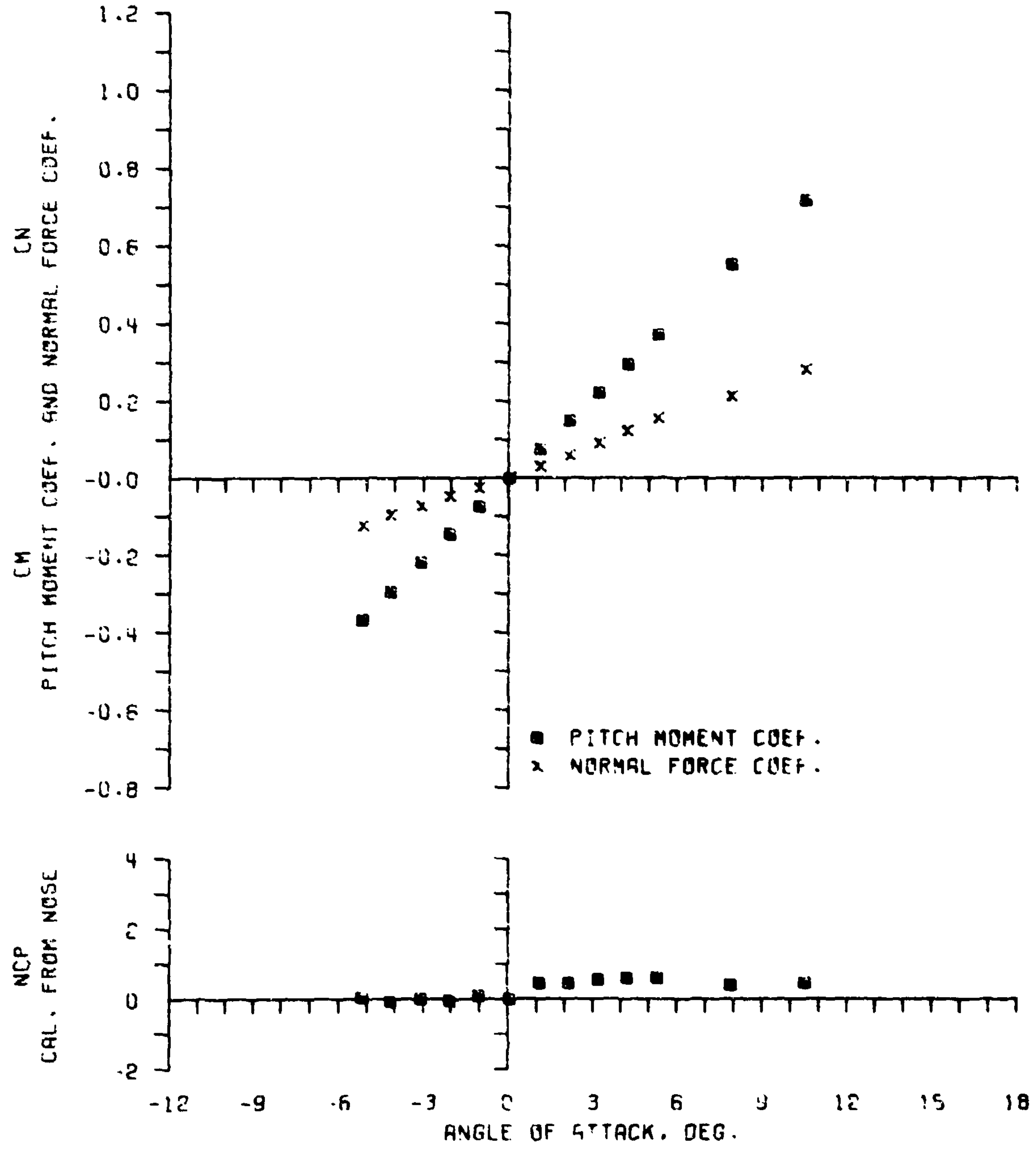
CONFIG= 5.10 RUN= 1.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.50 R(DIA) 0.88 X 10^6



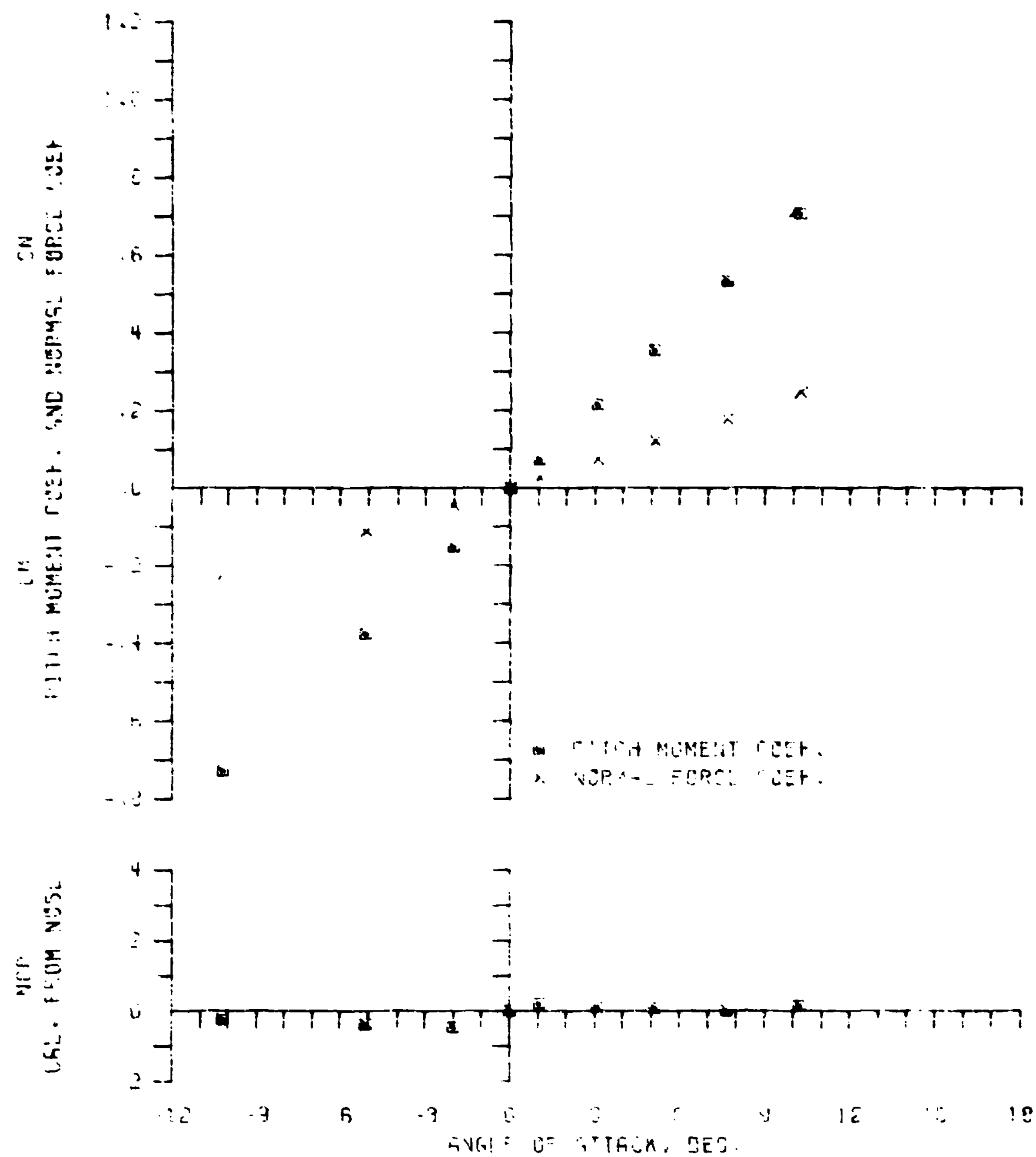
CONFIG= 5.10 RUN= 3.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.50 R(D)(A) 1.00 X 10^6



CONFIG= 5.10 RUN= 58.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH .50   RE/DIA .17 X 10^6



CONFIG. 5 ... RUN= 5.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.70 RE(DIA) 0.55 X 10^6

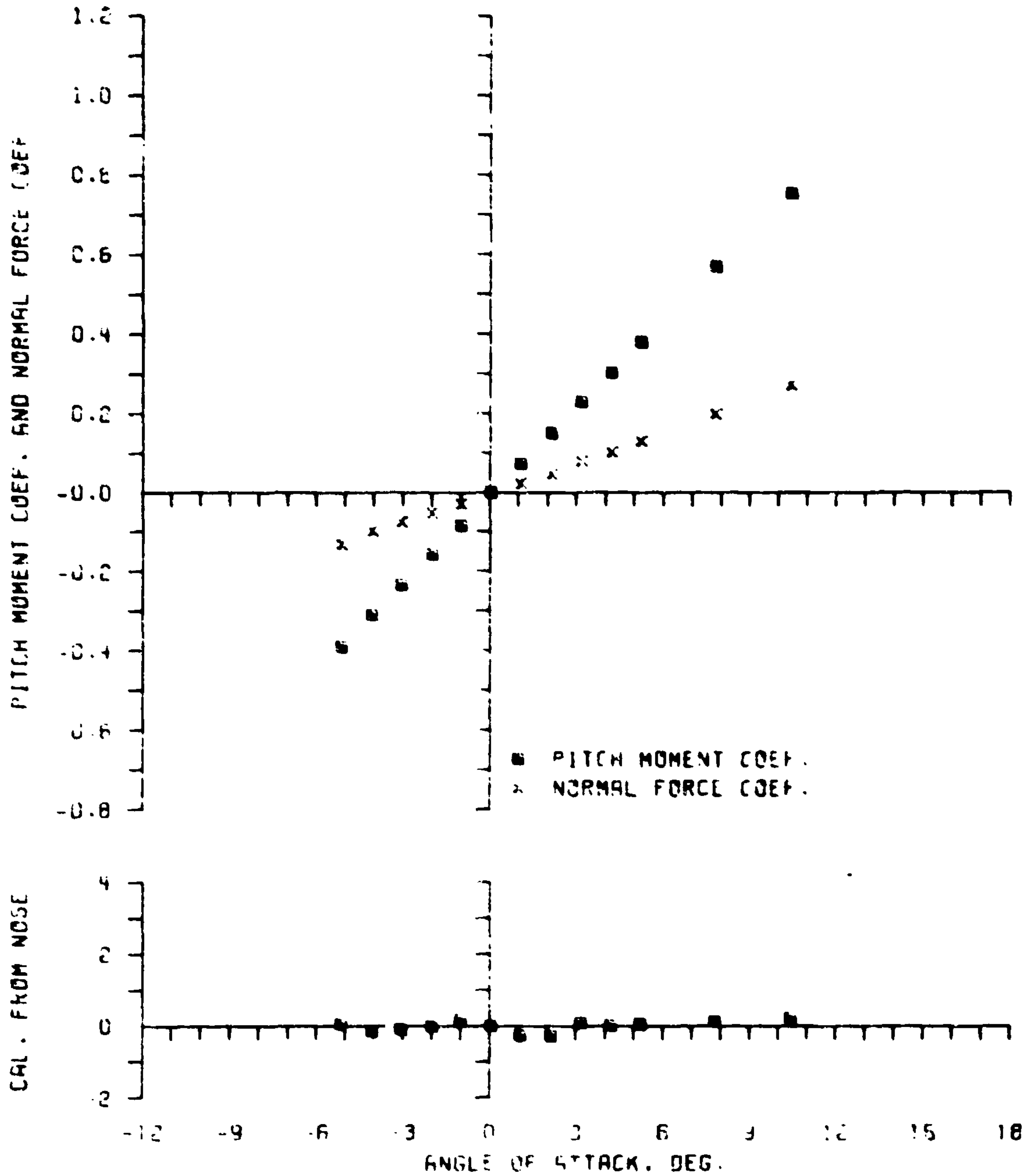
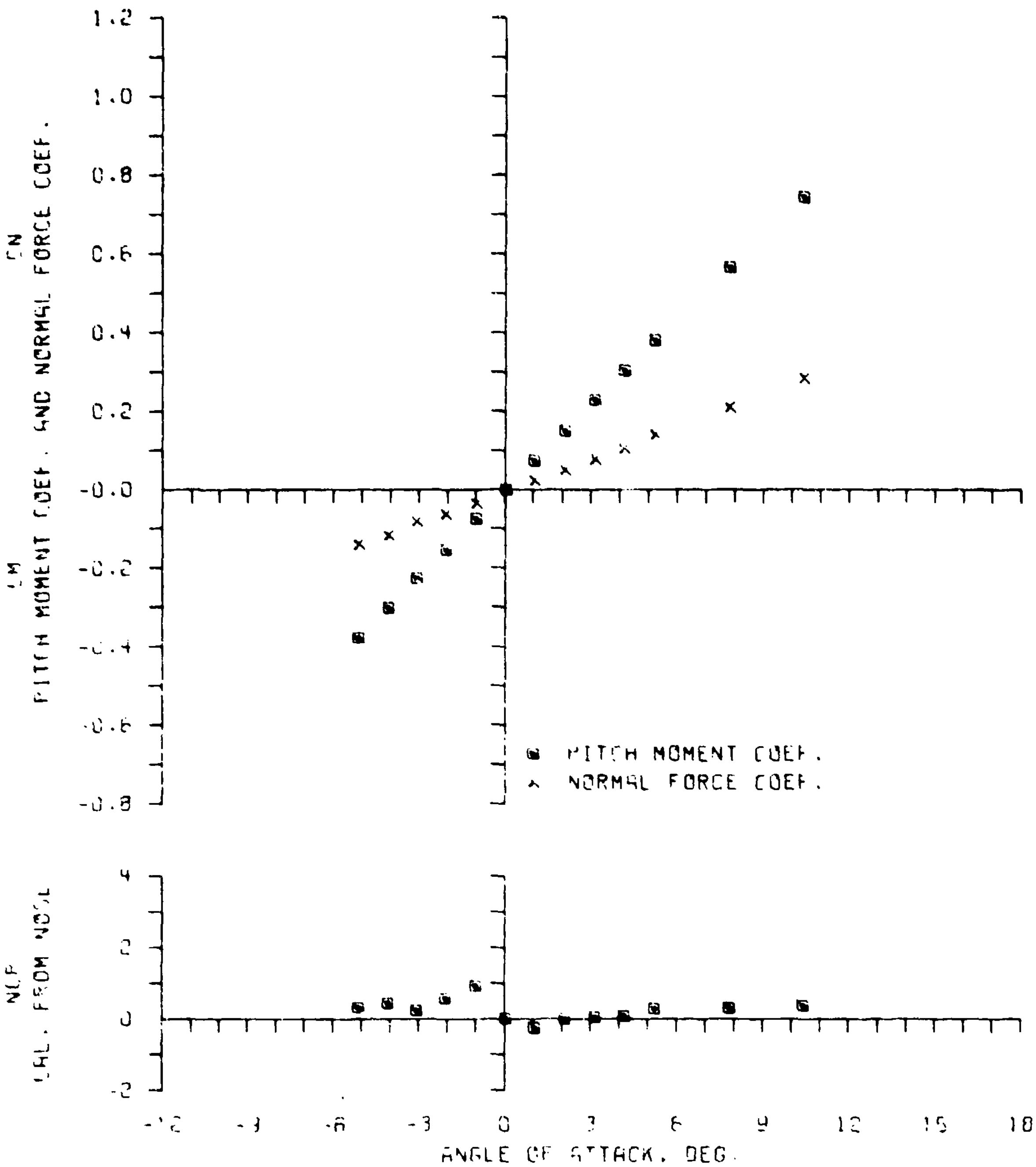


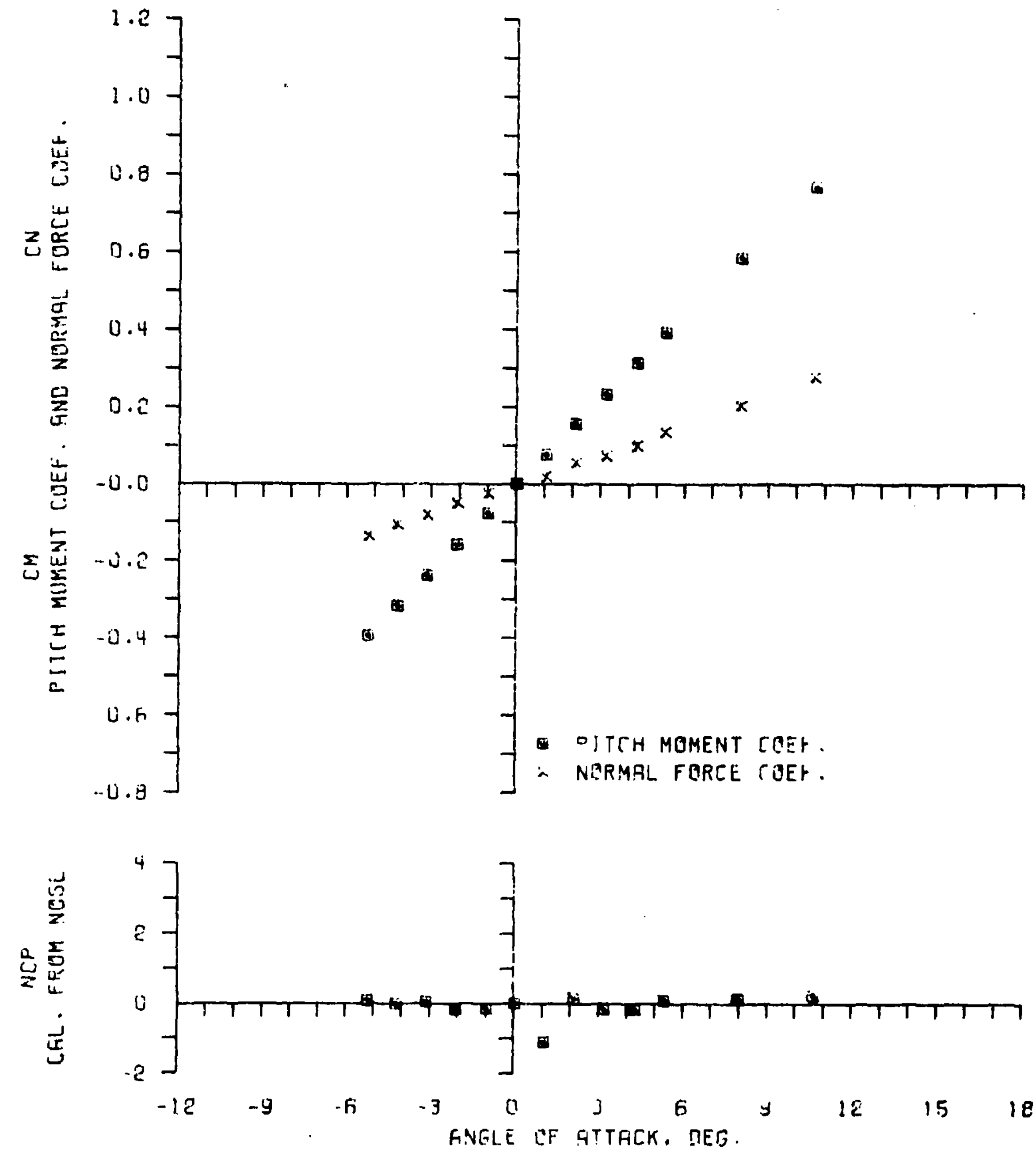
FIG. 5.10 RUN: 2.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.70 R(DIA) 0.57 X 10^6



CONFIG= 5 10 RUN= 57.

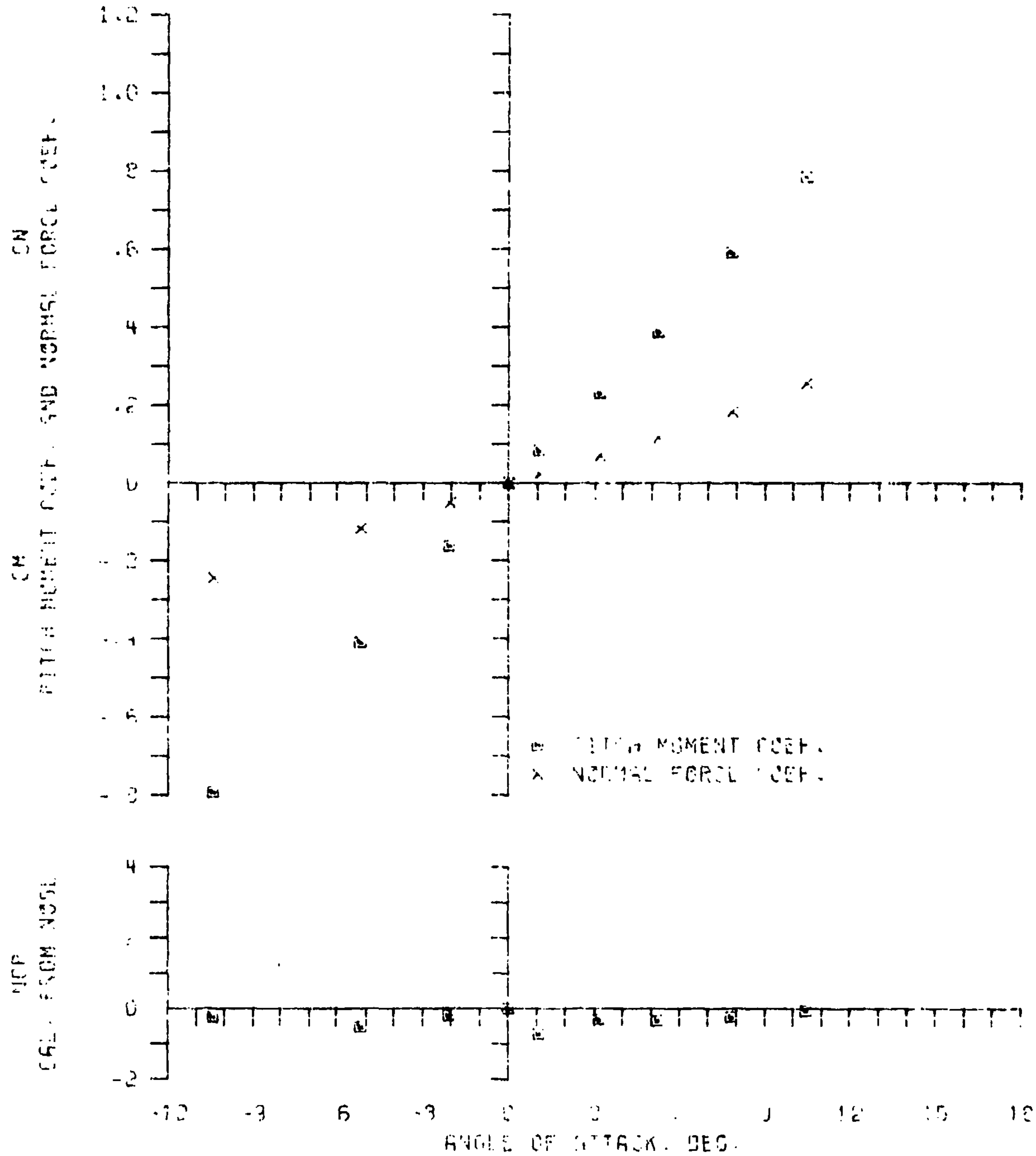
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.70 R(DIA) 0.86 X 10^6



CONFIG= 5.10 RUN= 4.

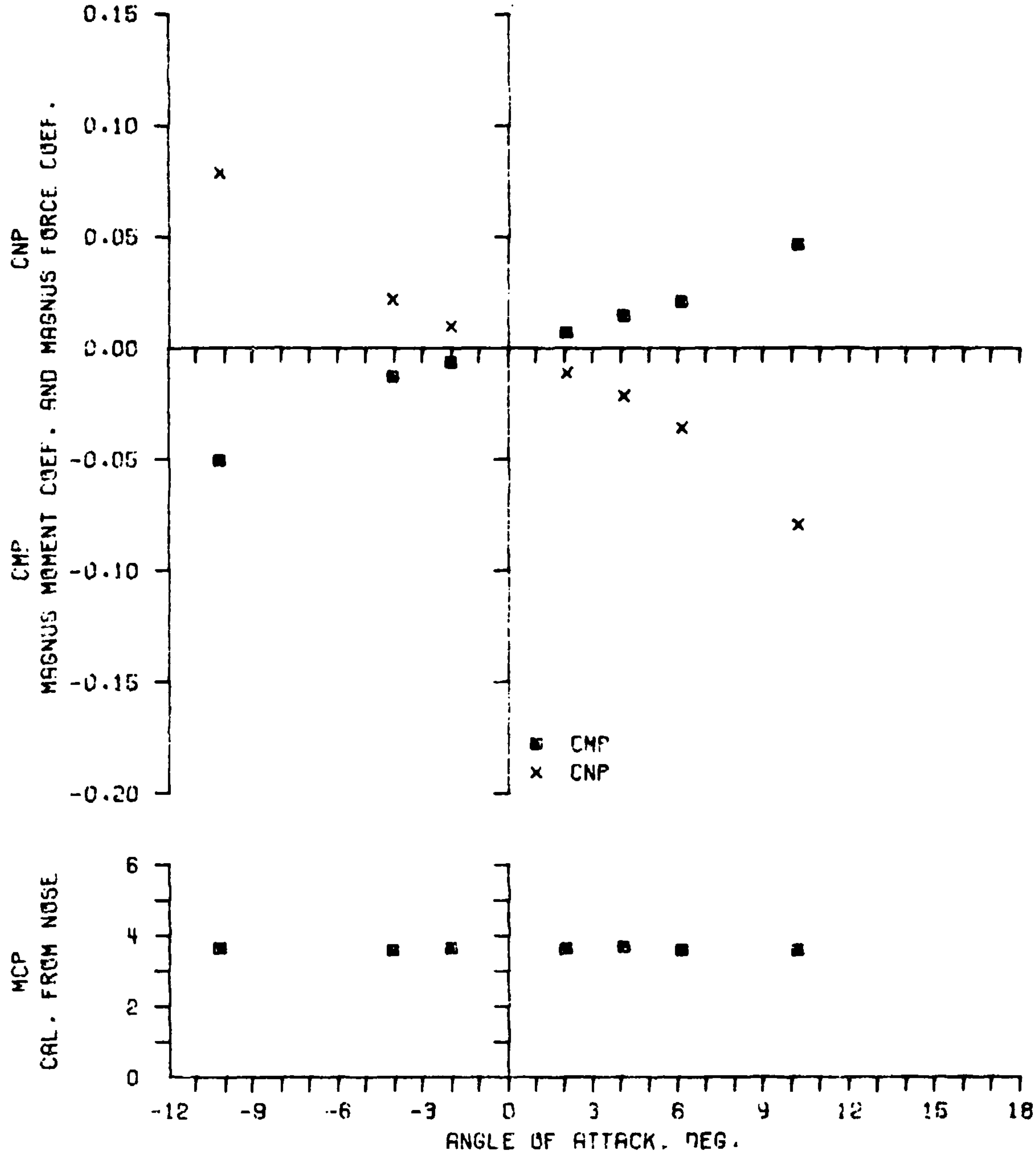
59

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, BRL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH .80   R/DIA .65 X 10^6



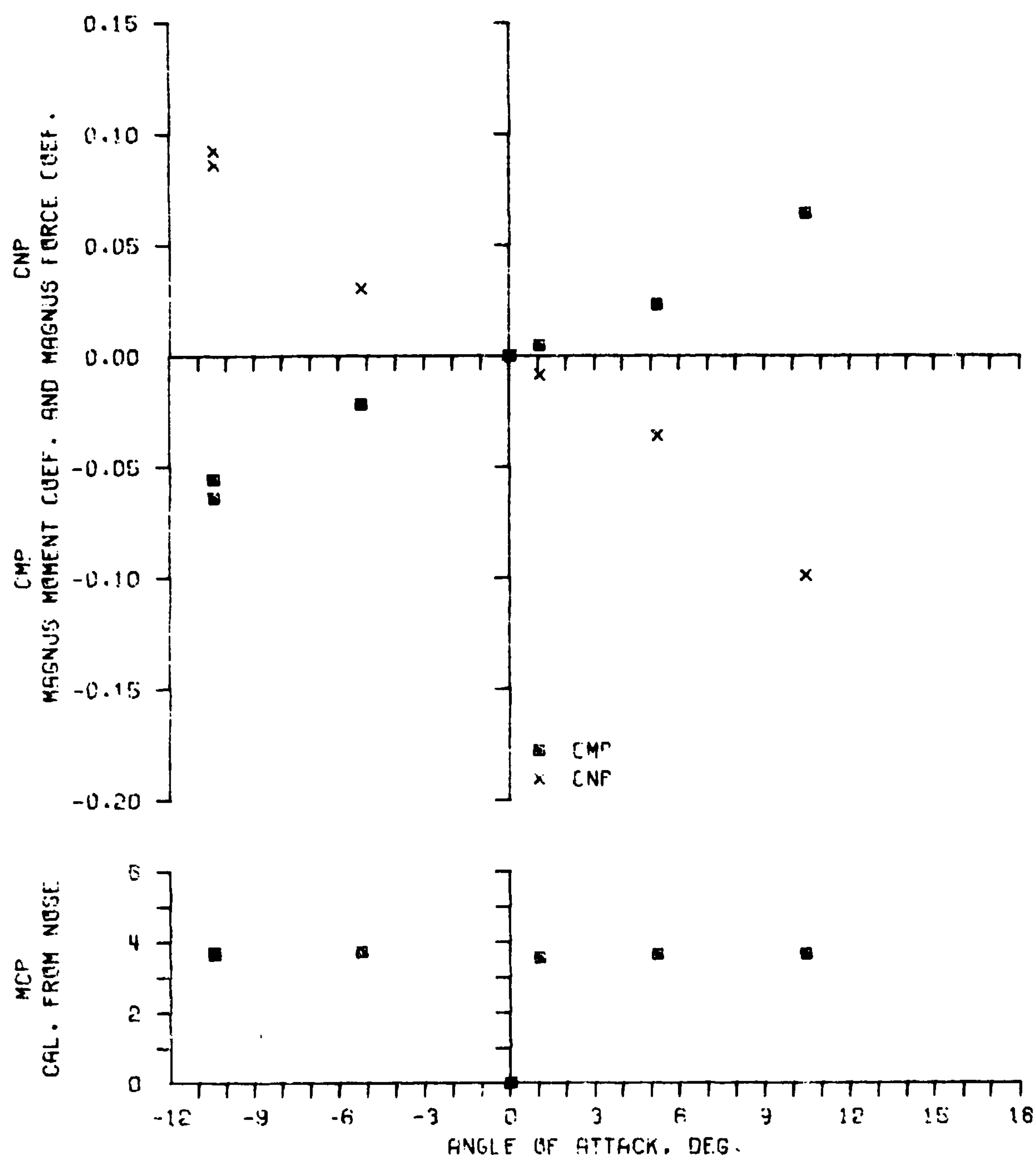
CONFIG= 5 12 RUN= 1.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.50 PD/V 0.67 R(DIA) 0.48 X 10^6



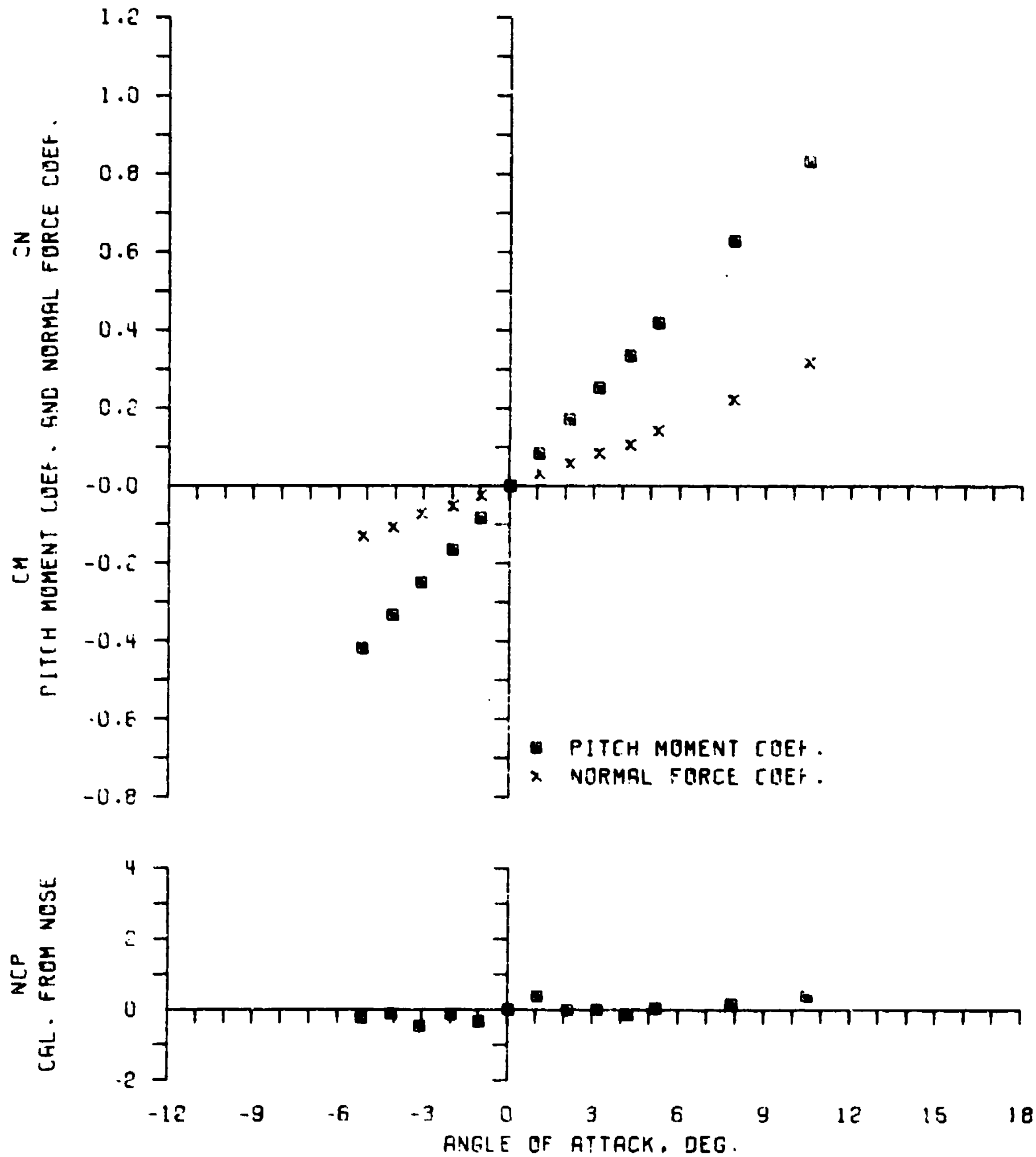
CONFIG= 5.10 RUN= 6.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.80 PD/V 0.42 R(DIA) 0.60×10^6



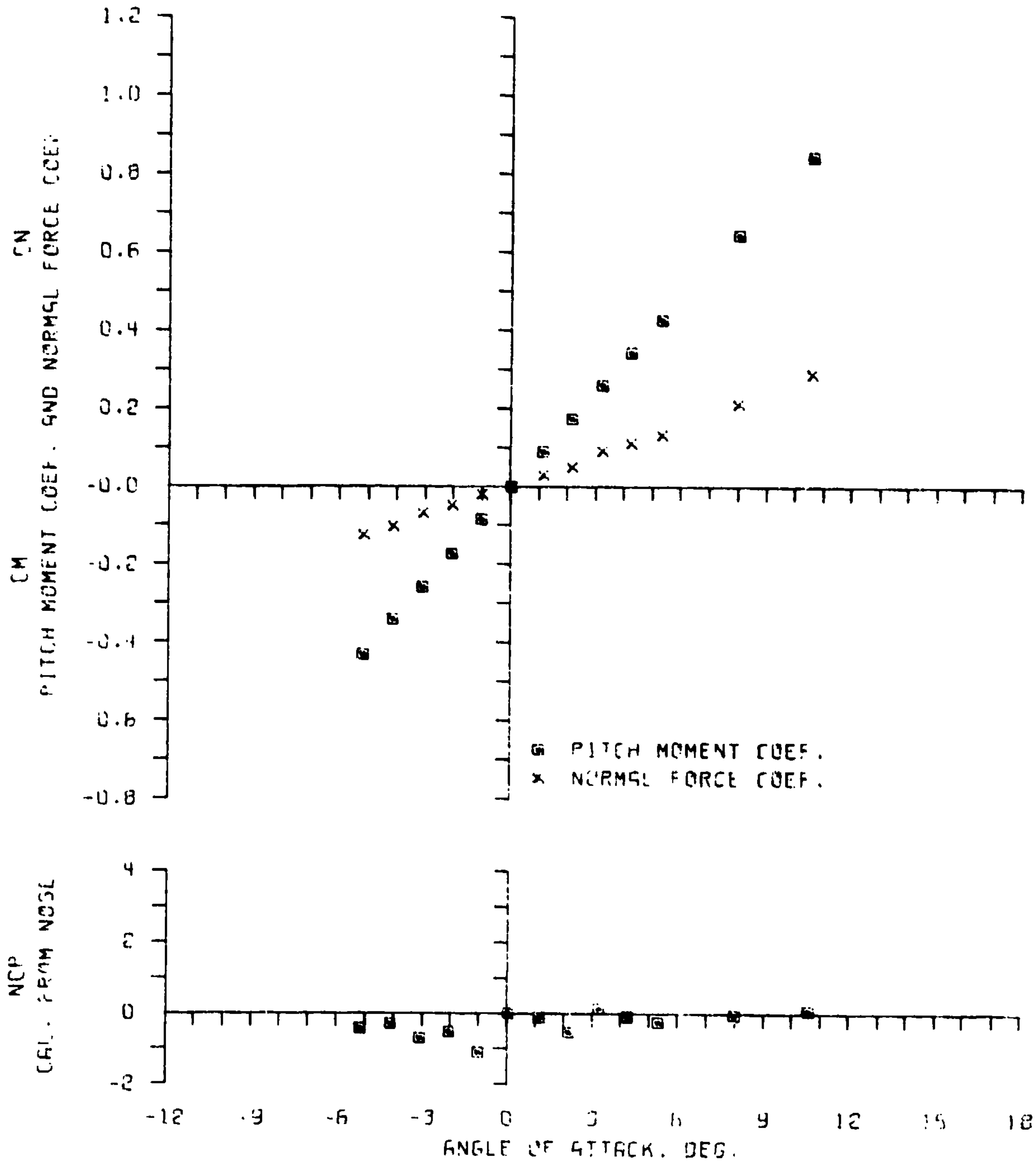
CONFIG= 5.10 RUN= 2.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 0.90 R(DIA) 0.48 X 10^6



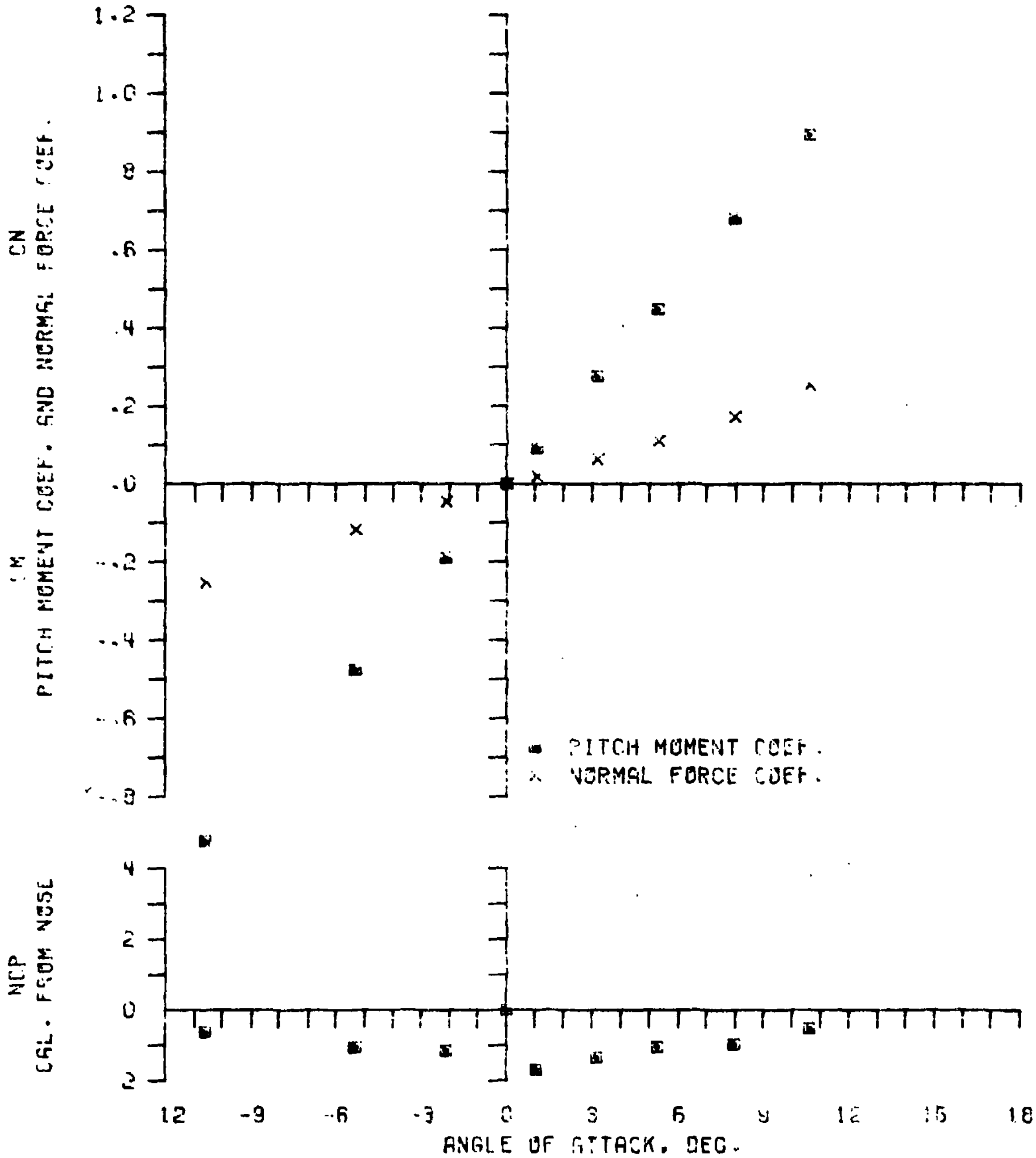
CONFIG= 5.10 RUN= 56.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. ONE CAL. 7 DEG. BOATTAIL
MACH 0.90 R(DIA) 0.56 X 10^6



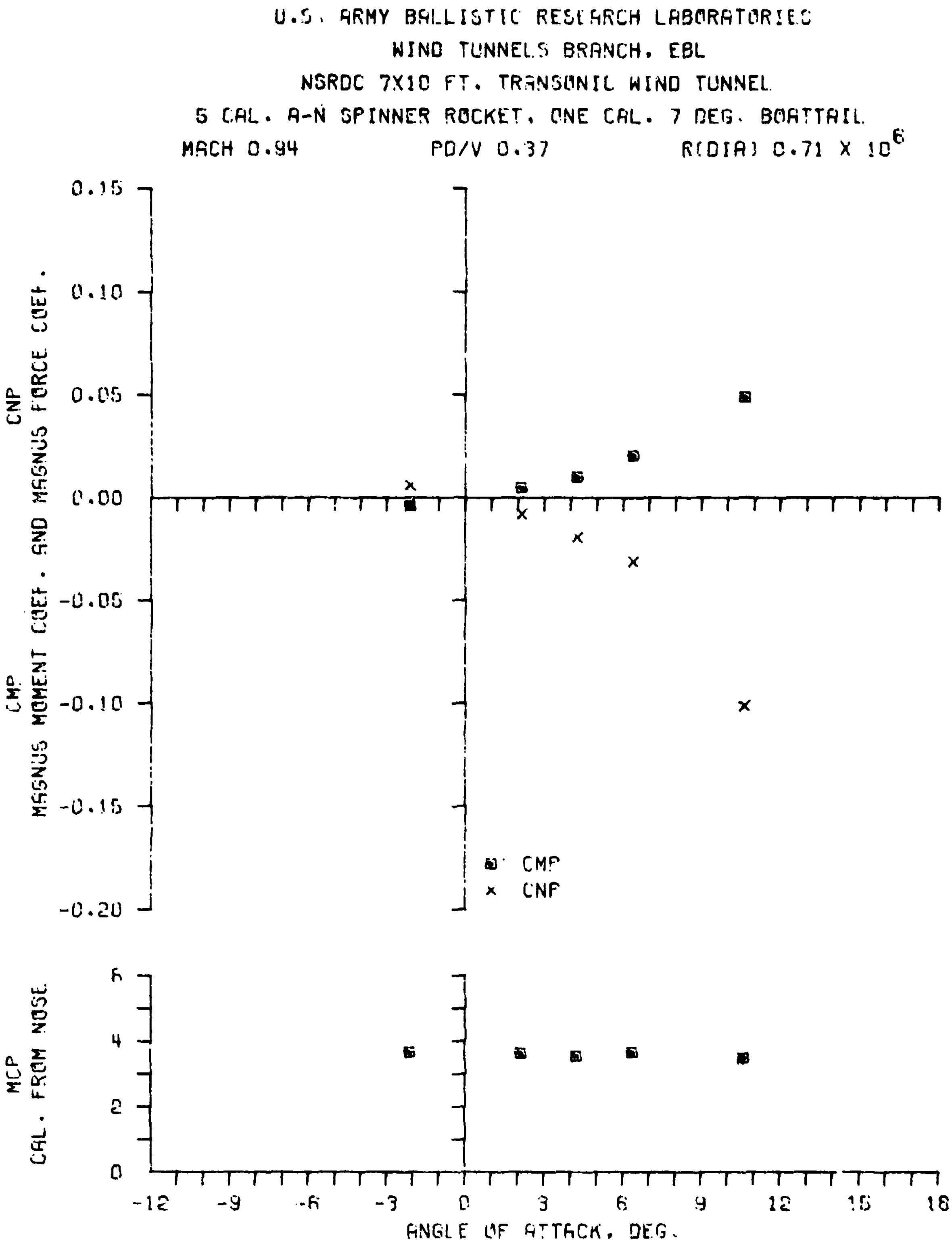
CONFIG= 5.10 RUN= 5.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH .94 R(DIA) .72 X 10^6



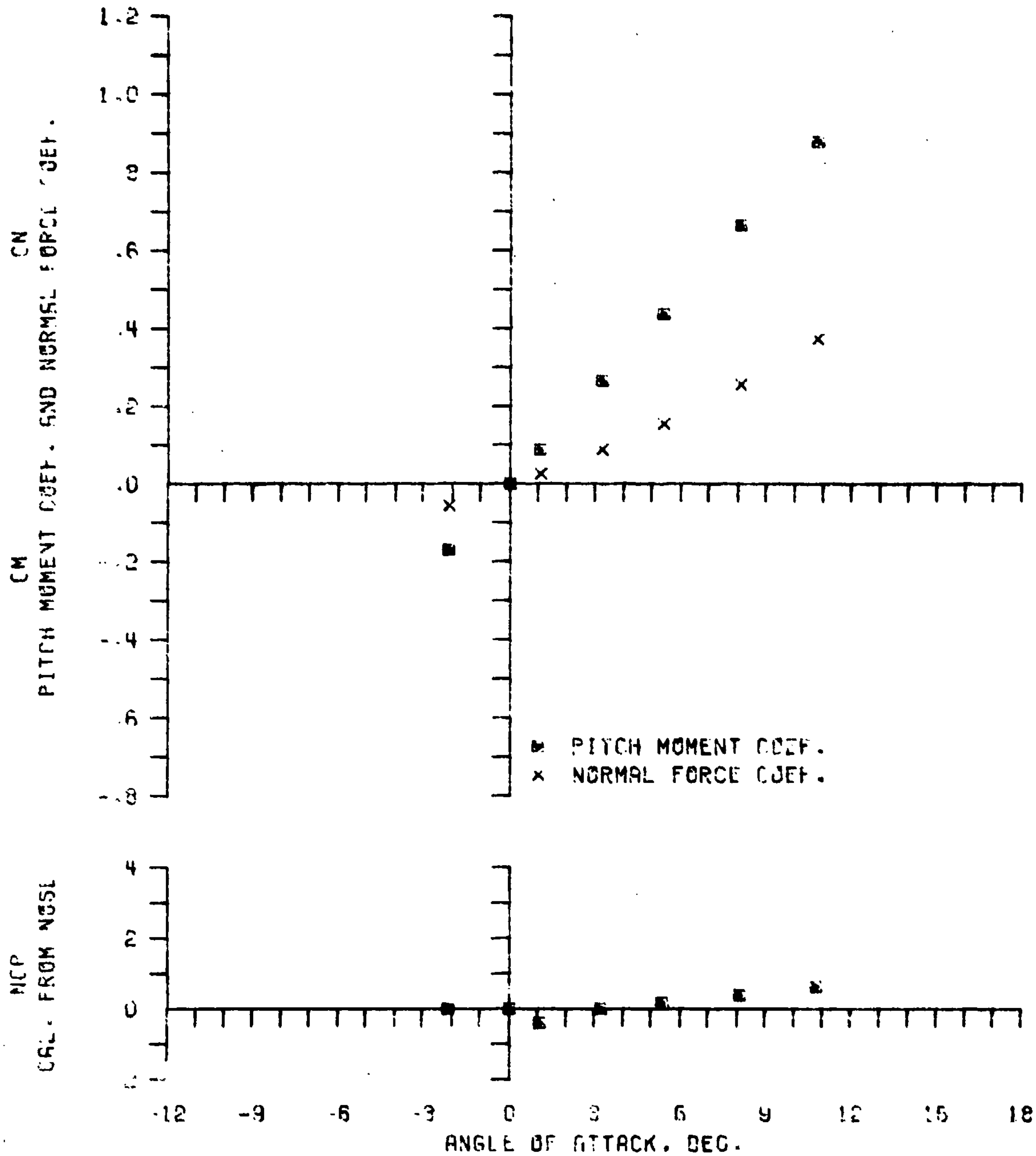
CONFIG= 3 10 RUN= 7.

66



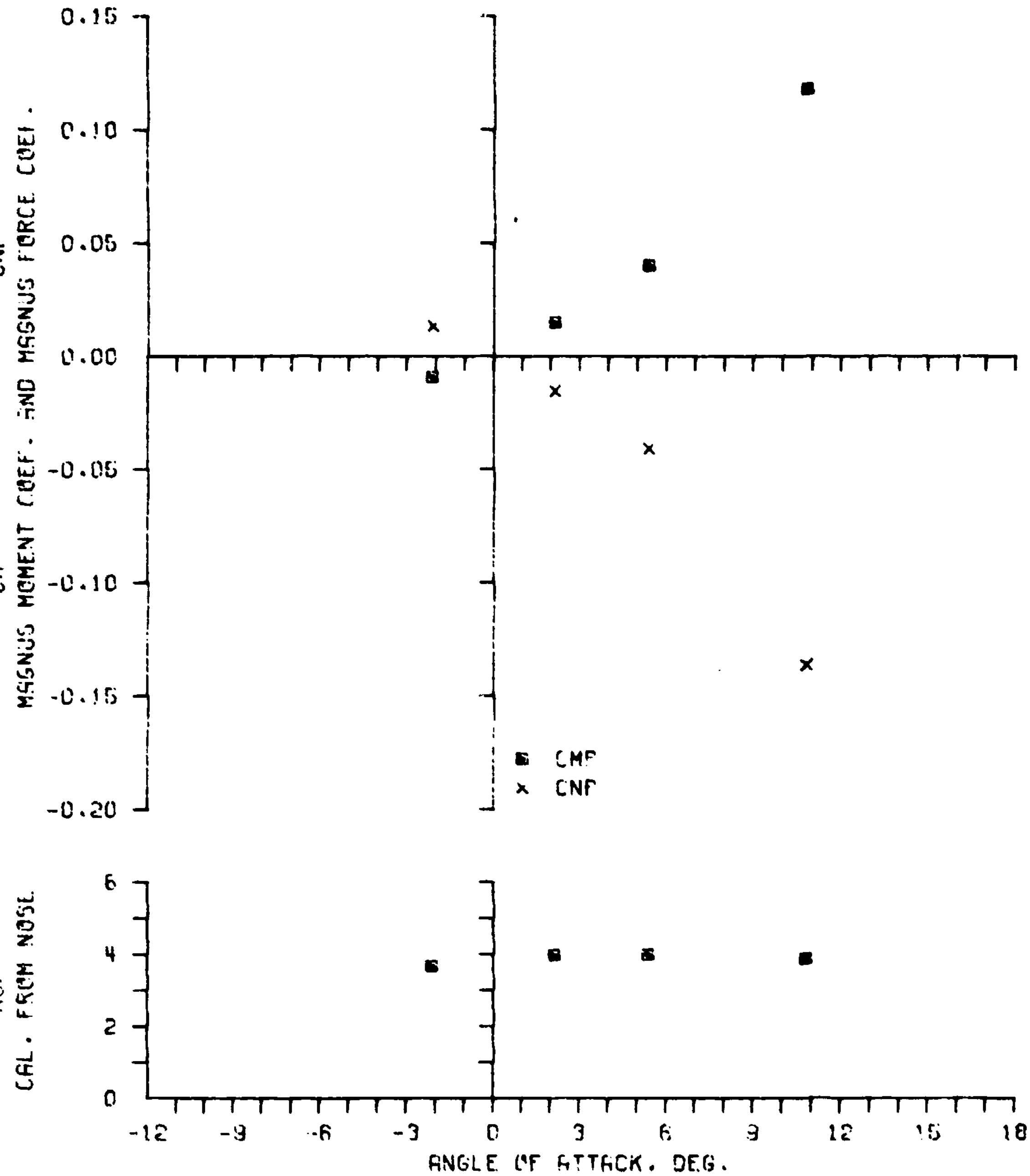
CONFIG= 5.10 RUN= 8.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 1.15 R/DIA) .67 X 10^6

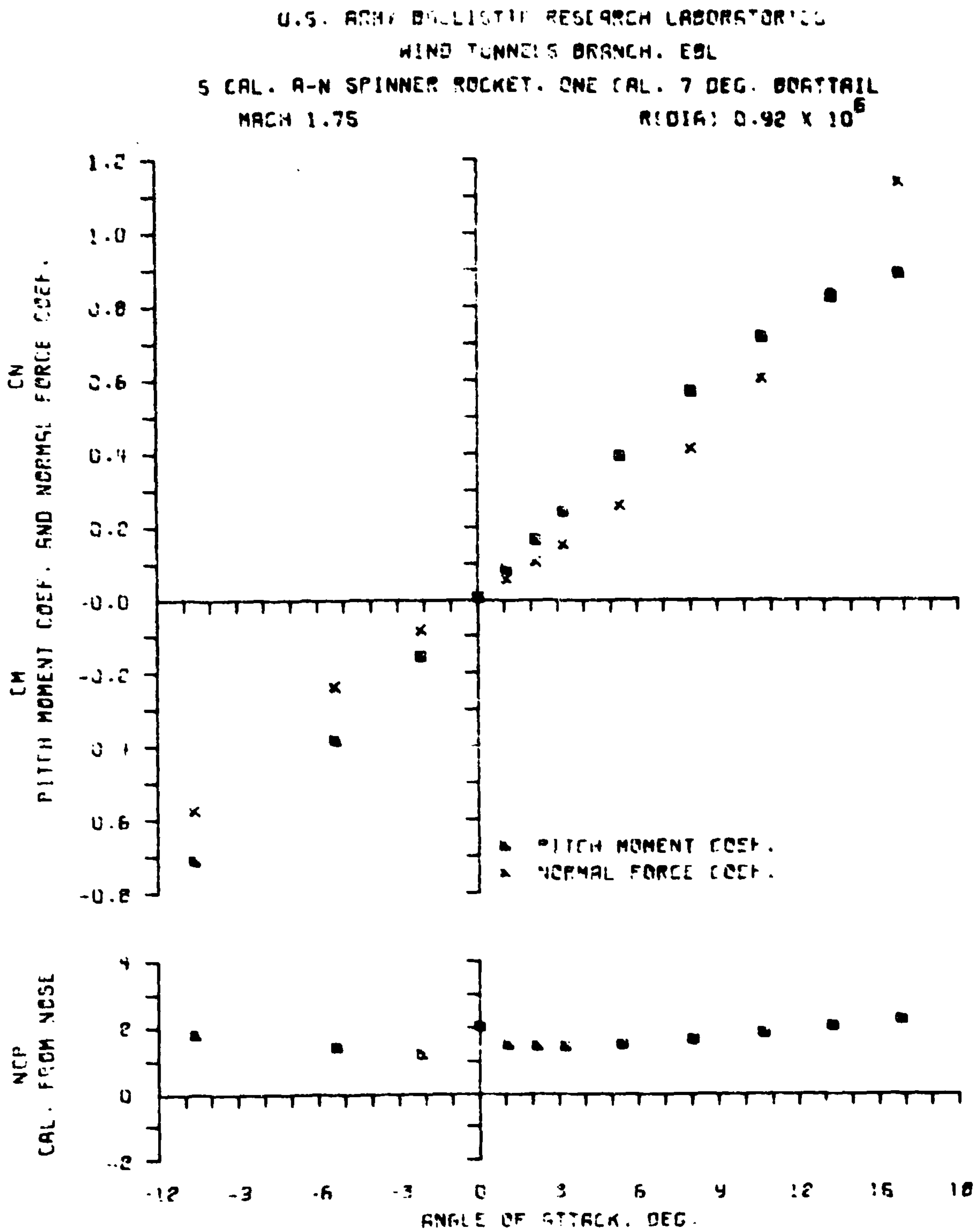


CONFIG= 5.10 RUN= 3.

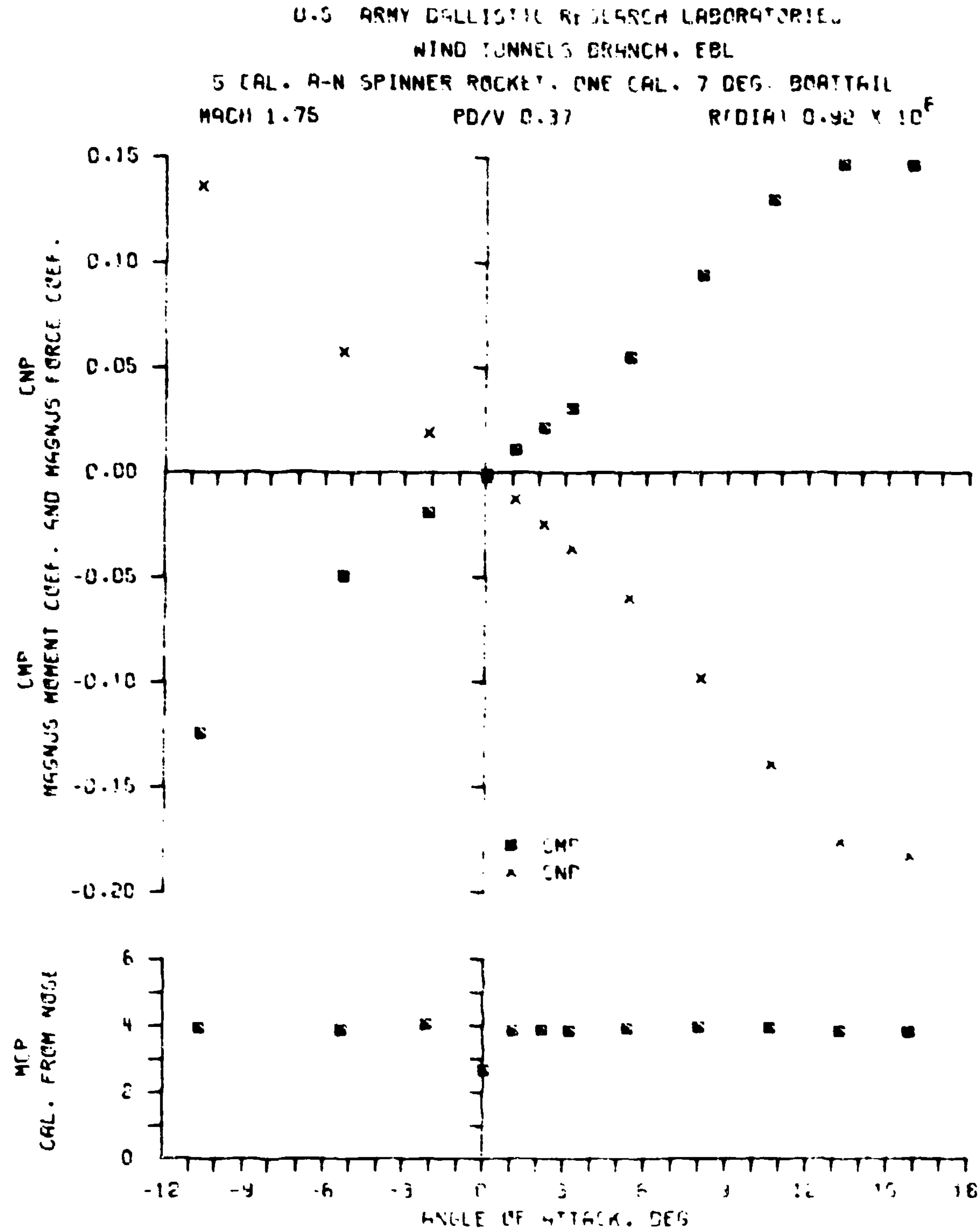
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 1.15 PD/V 0.31 R(DIA) 0.66 X 10^6



CONFIG= 5.10 RUN= 4.

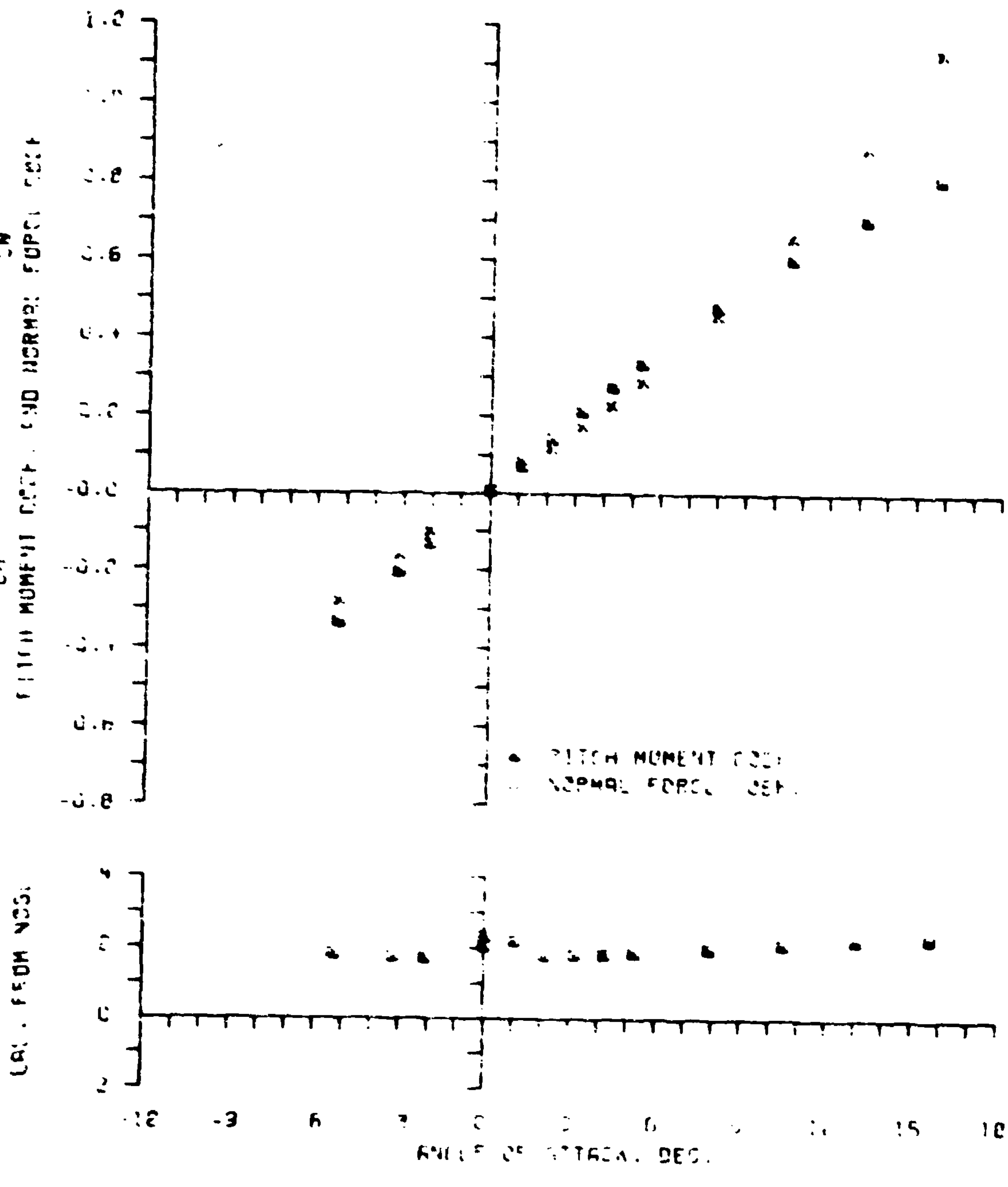


CONFIG= 5.10 RUN= 1.



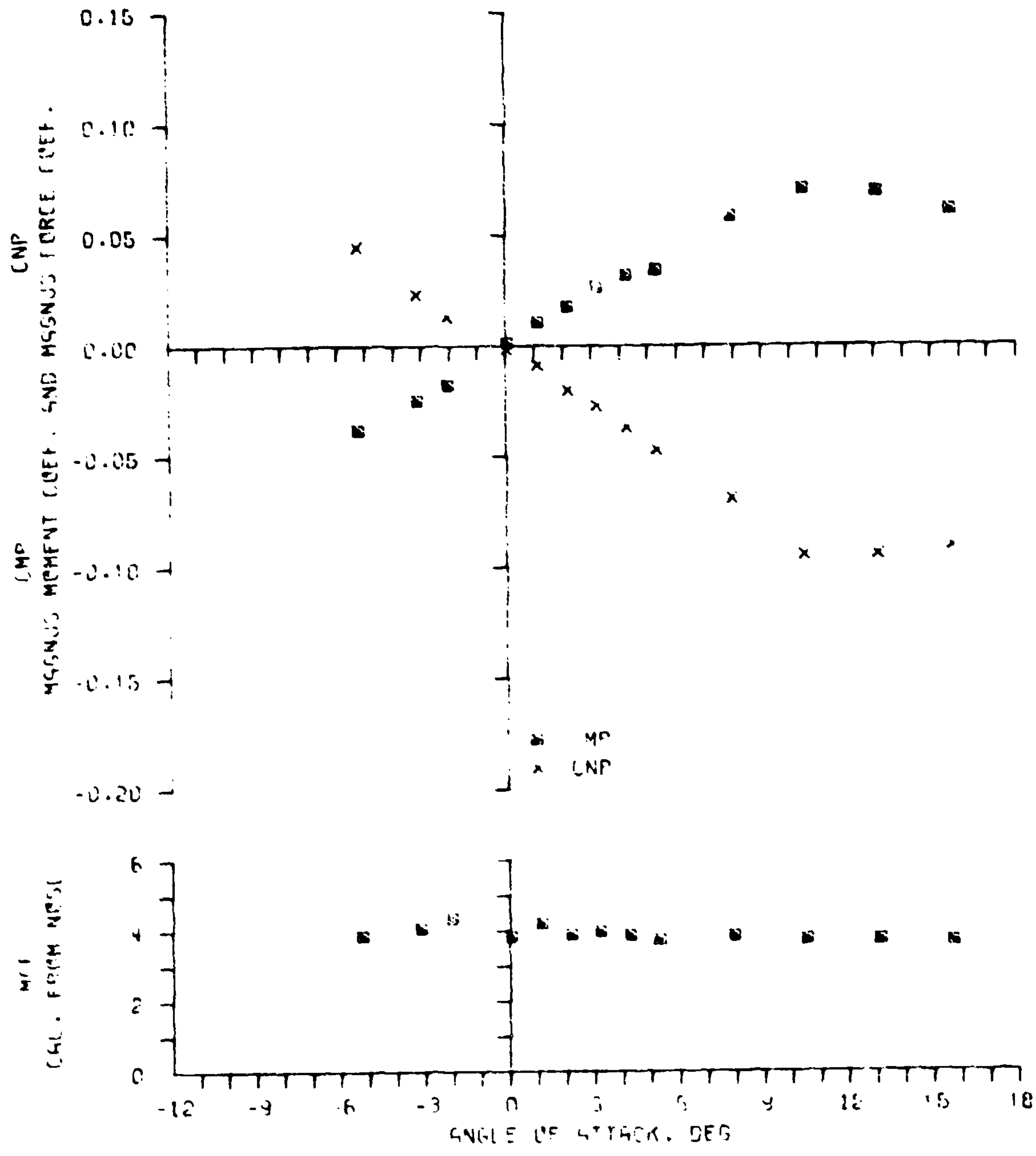
CONFIG= 5.10 RUN= 1.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNEL BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, 2ND CAL. 7 DEG. BOATTAIL
MACH 2.50 RE/DIA: 0.94 X 10^6

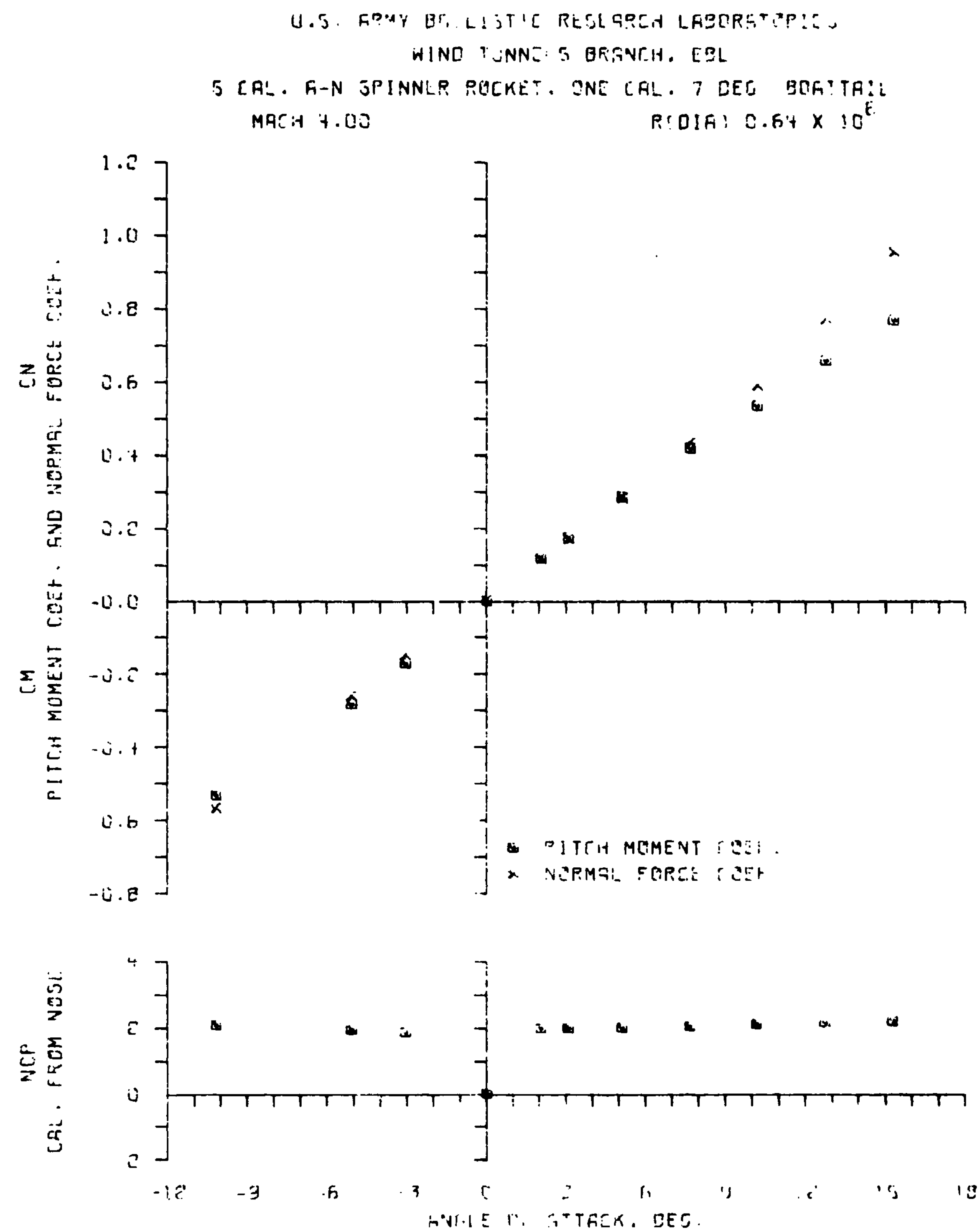


CONFIG. 5 10 RUN= 2.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 2.50 PD/V 0.31 R(DIA) 0.94 X 10^6

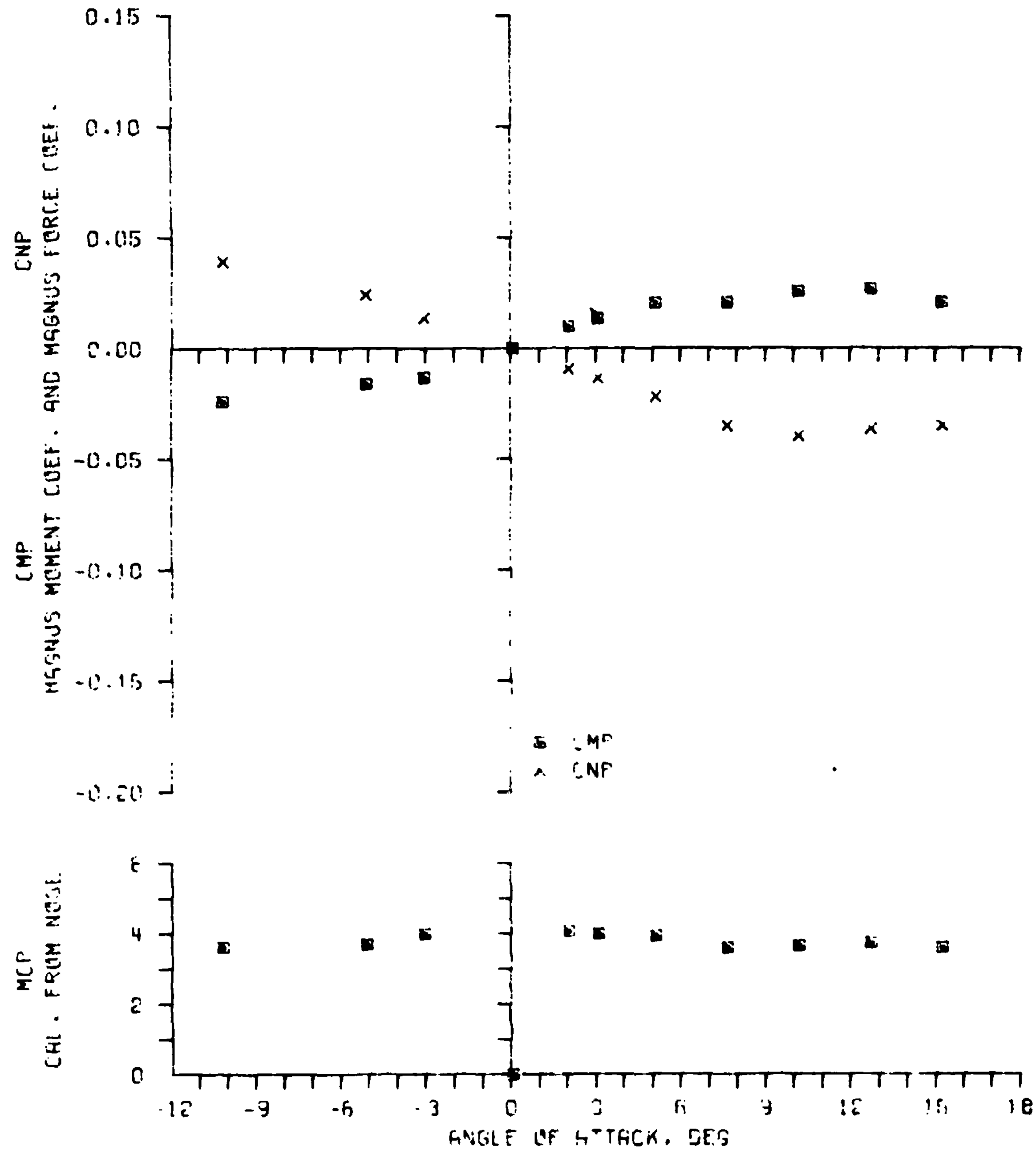


CONFIG= 5 10 RUN= 2

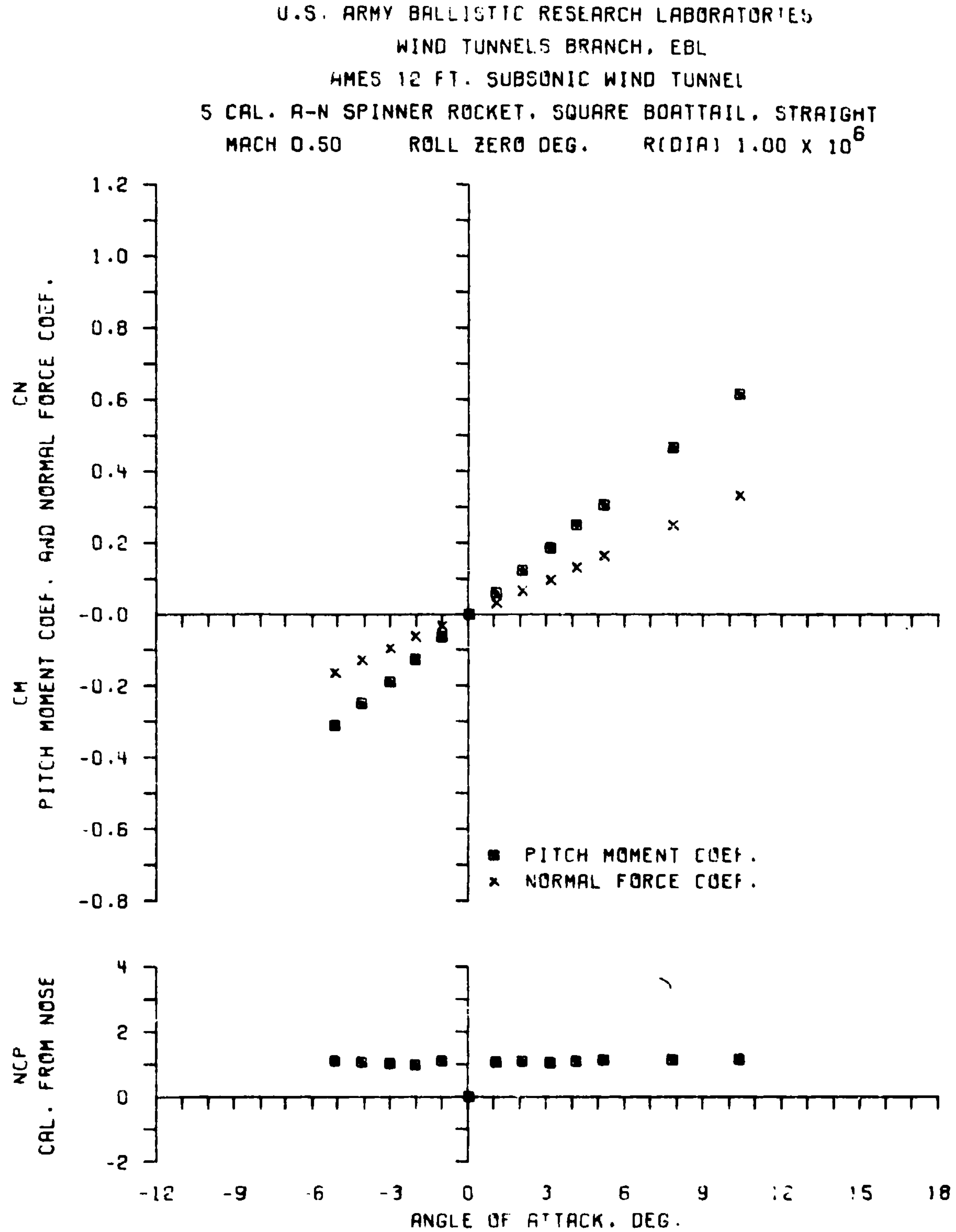


CONFIG. 6 ID RUN= 3.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, ONE CAL. 7 DEG. BOATTAIL
MACH 4.00 PD/V 0.26 R(DIA) 0.64 X 10^6

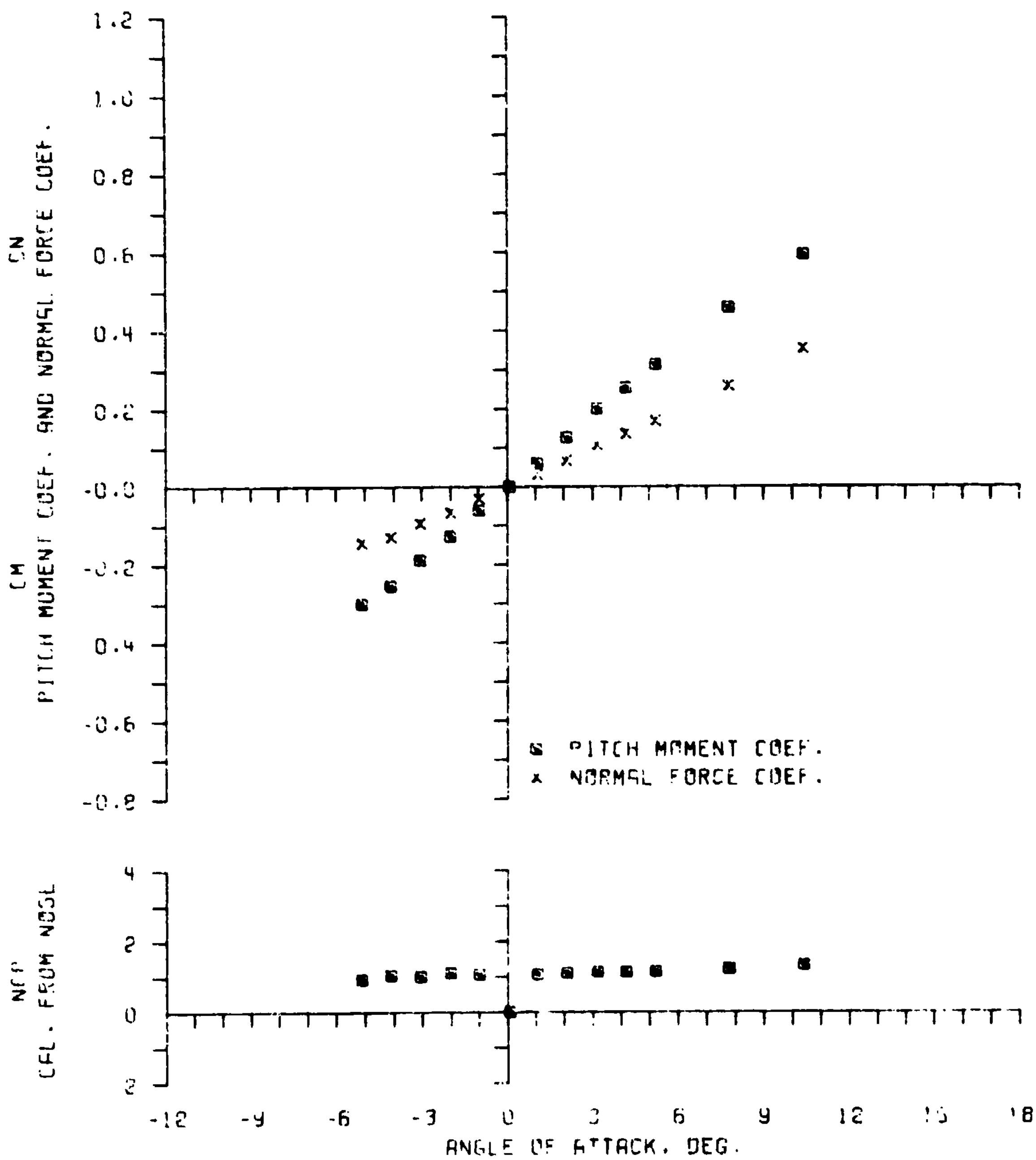


CONFIG= 5.10 RUN= 3.



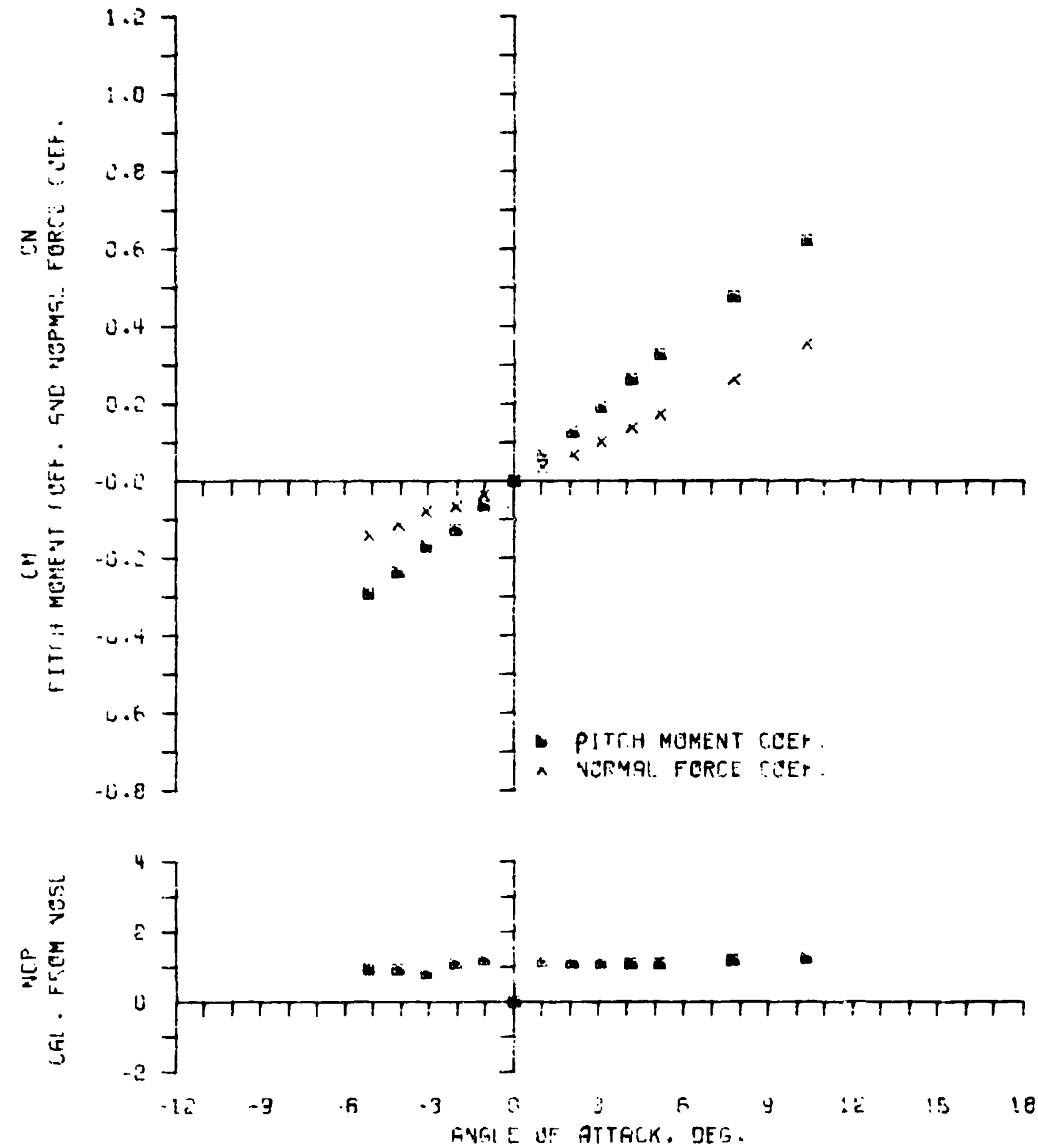
CONFIG= 5.20 RUN= 49.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH. EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAIL. STRAIGHT
MACH 0.50 ROLL 45 DEG. R(DIA) 1.00 X 10 ^{6}

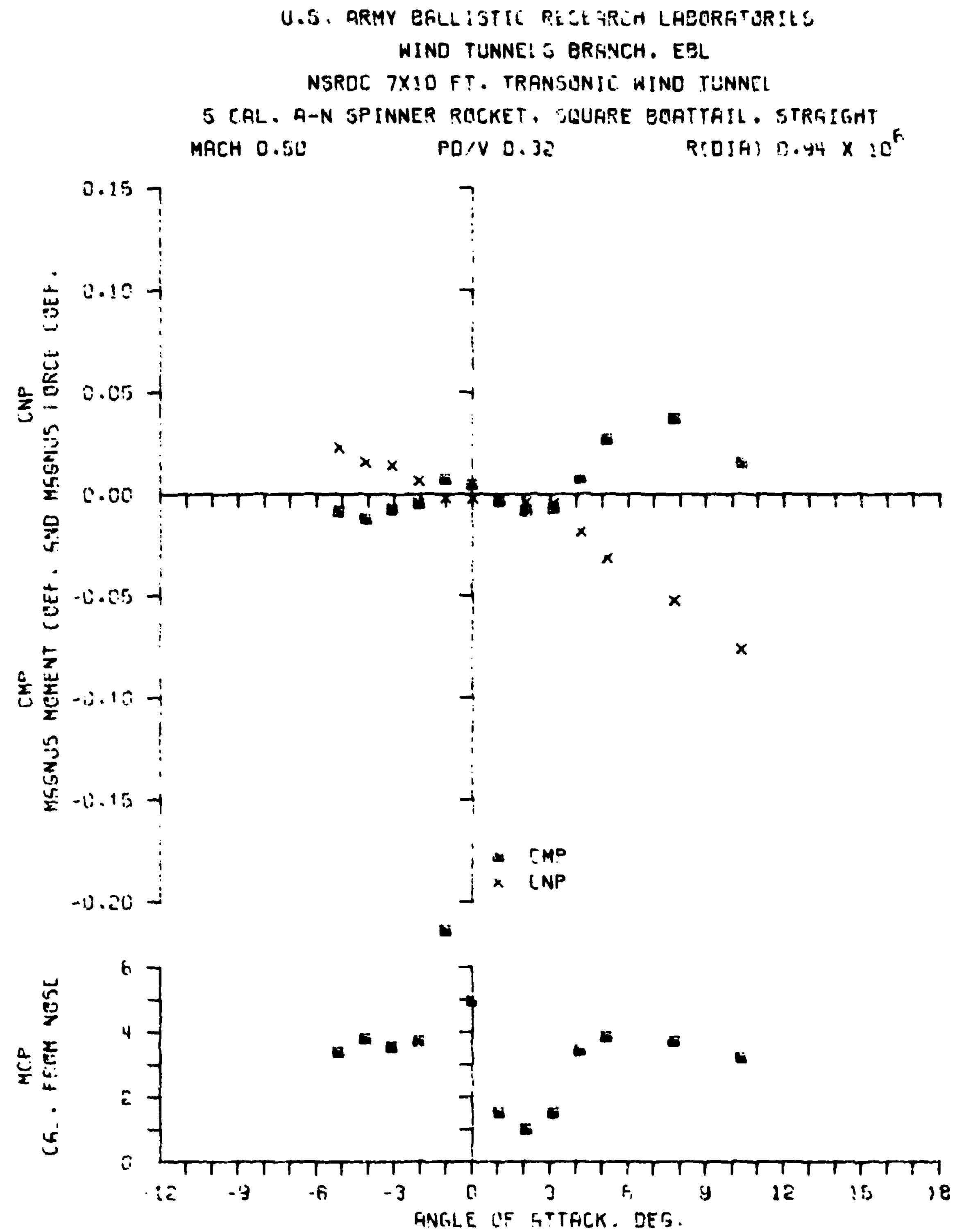


CONFIG= 5.20 RUN= 52

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL STRAIGHT
MACH 0.50 R/DIA: 0.99 X 10^6

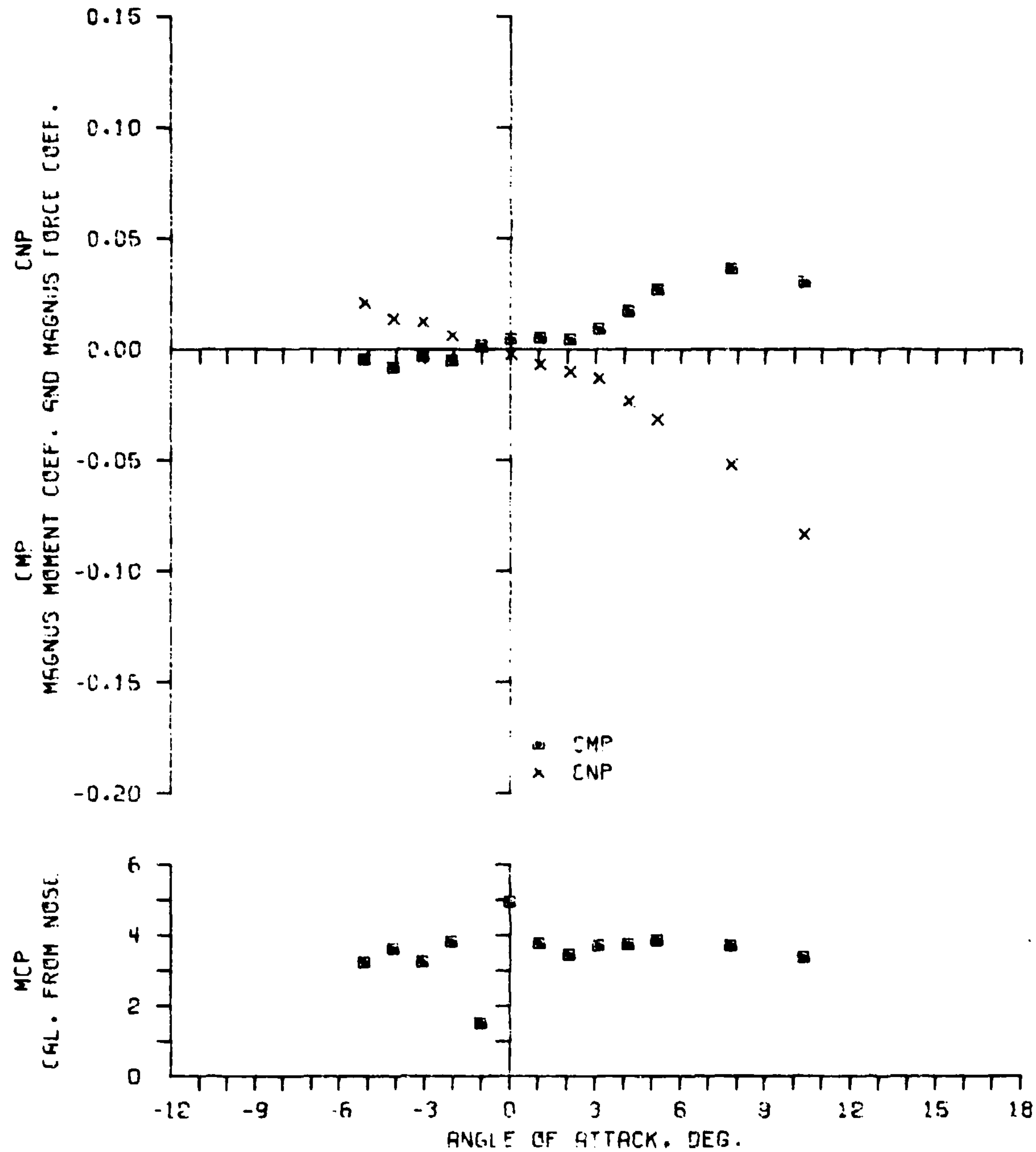


CONFIG= 5.20 RUN= 5.



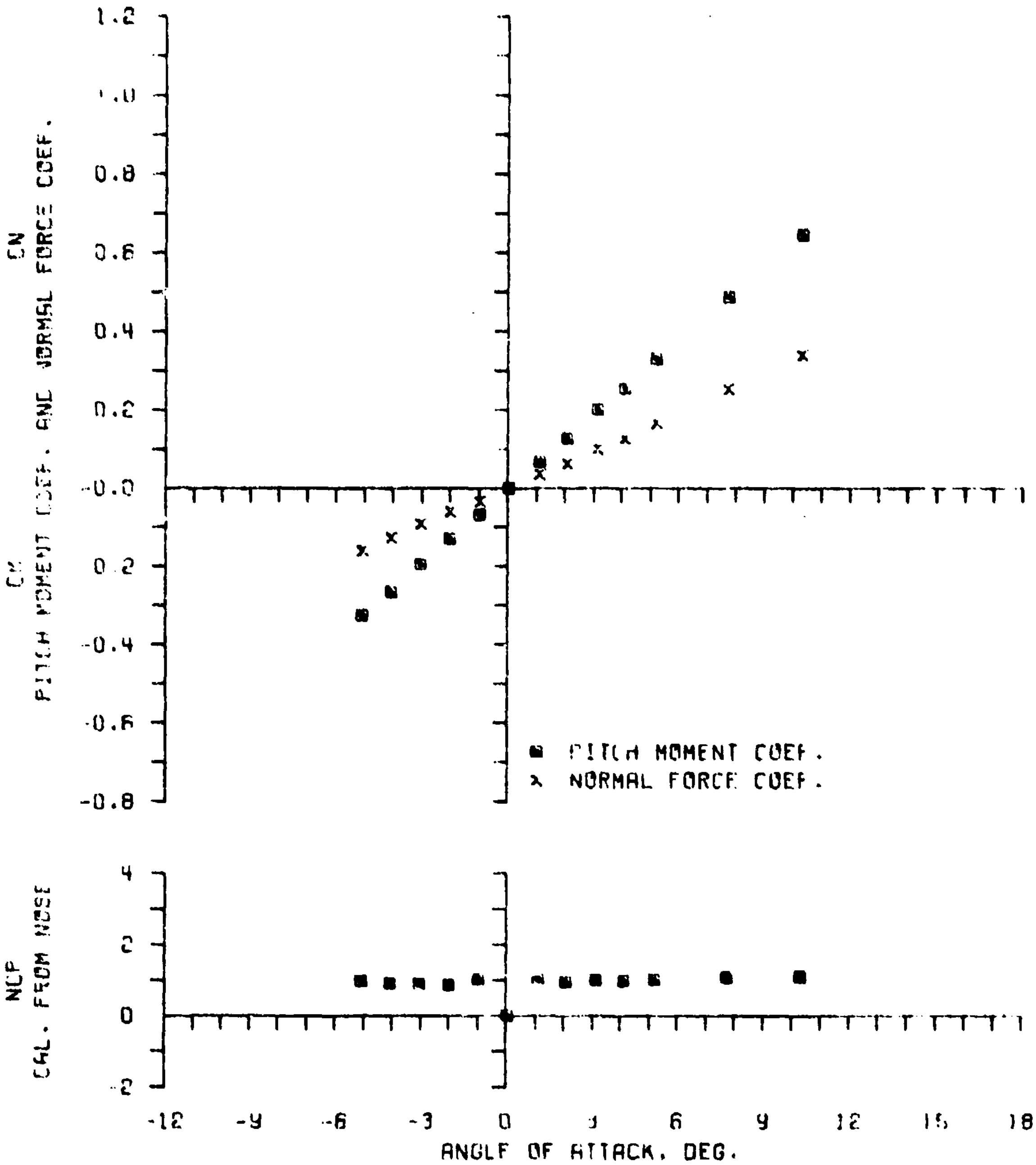
CONFIG= 5.20 RUN= 6.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.50 PD/V 0.64 R(DIA) 0.94 X 10^6



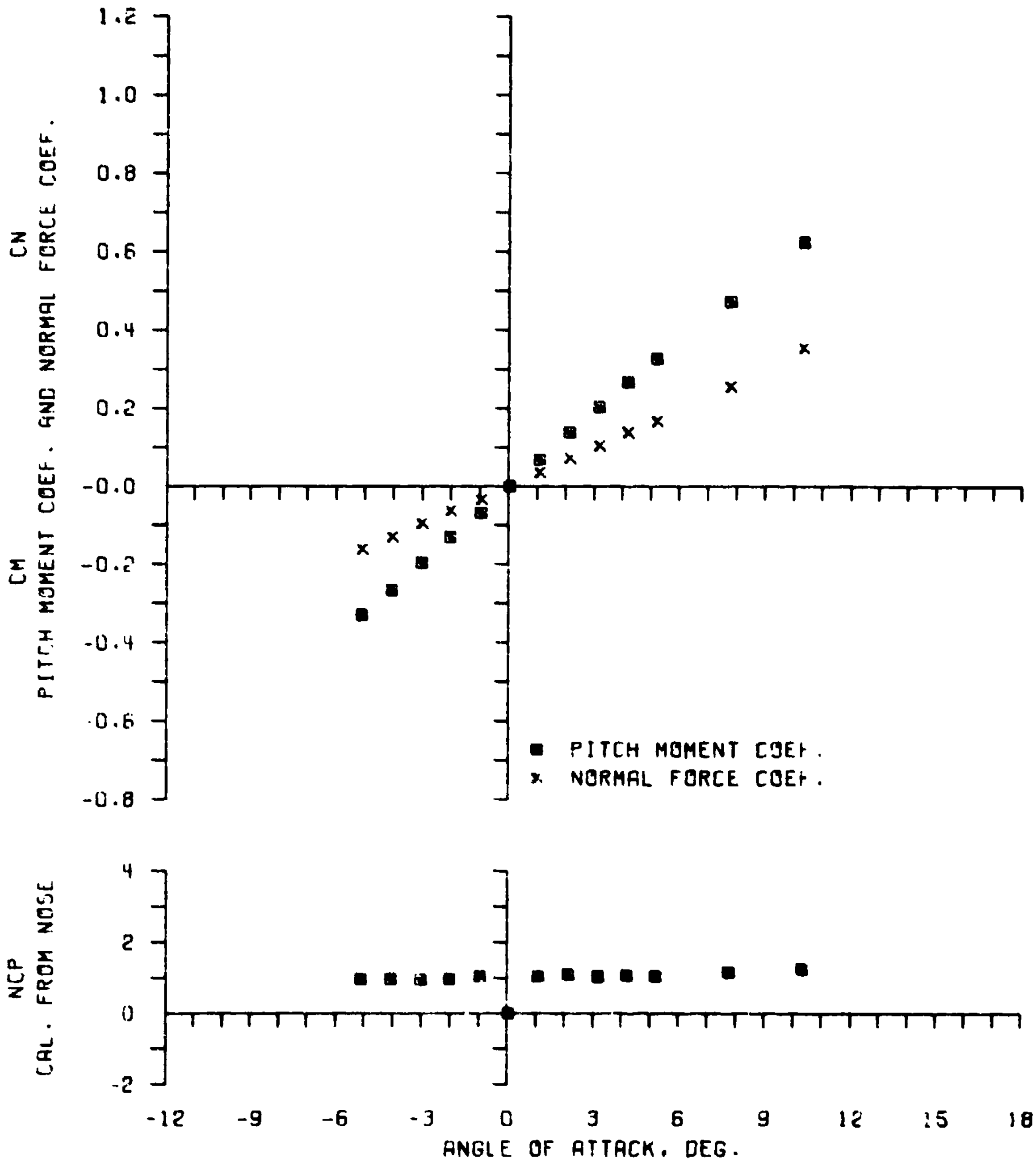
CONFIG= 5.20 RUN= 6.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.70   ROLL ZERO DEG.   R(DIA) 0.57 X 10^6



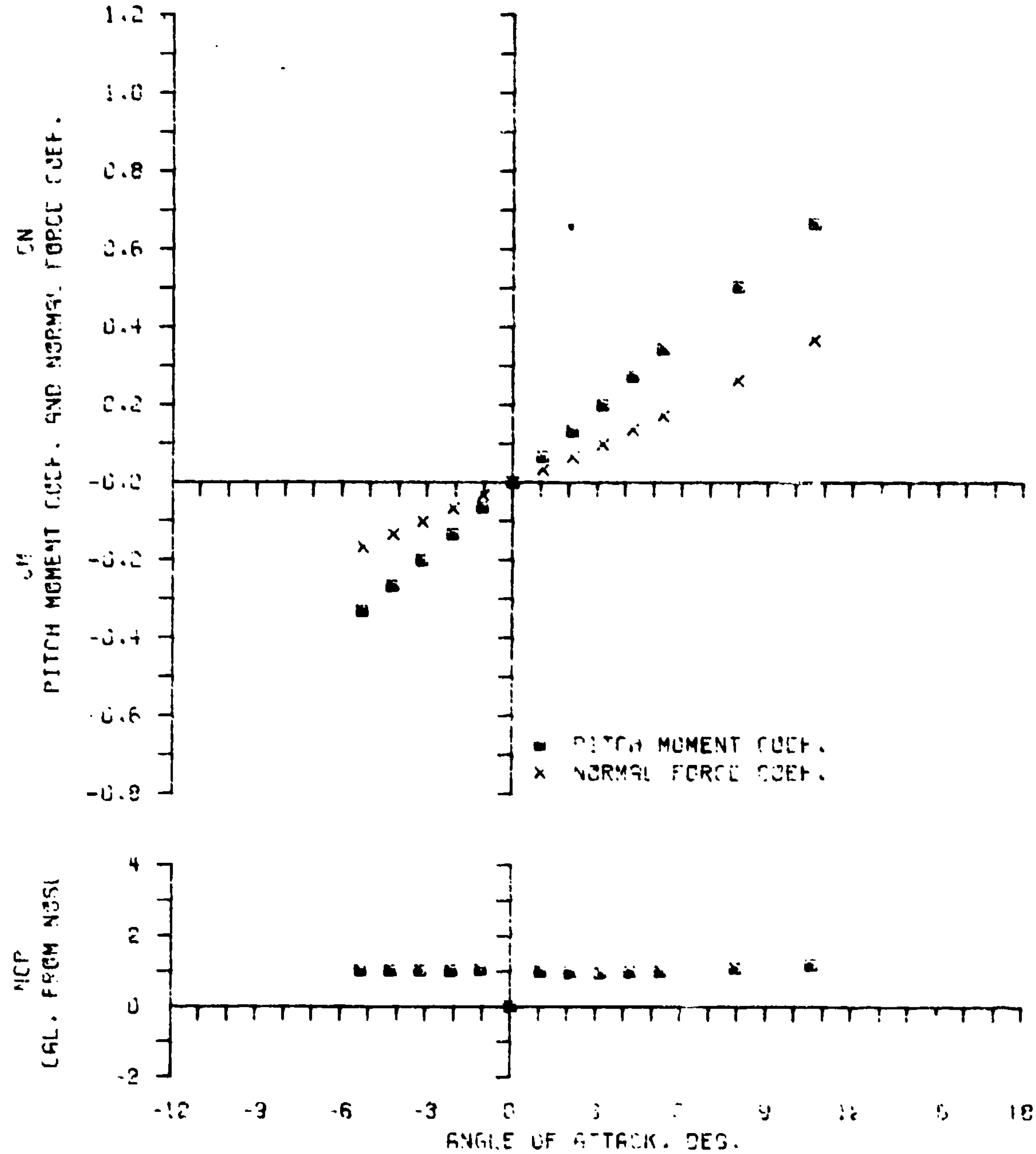
CONFIG. 5.20   RUN: 48.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.70 ROLL 45 DEG. R(DIA) 0.56 X 10 6



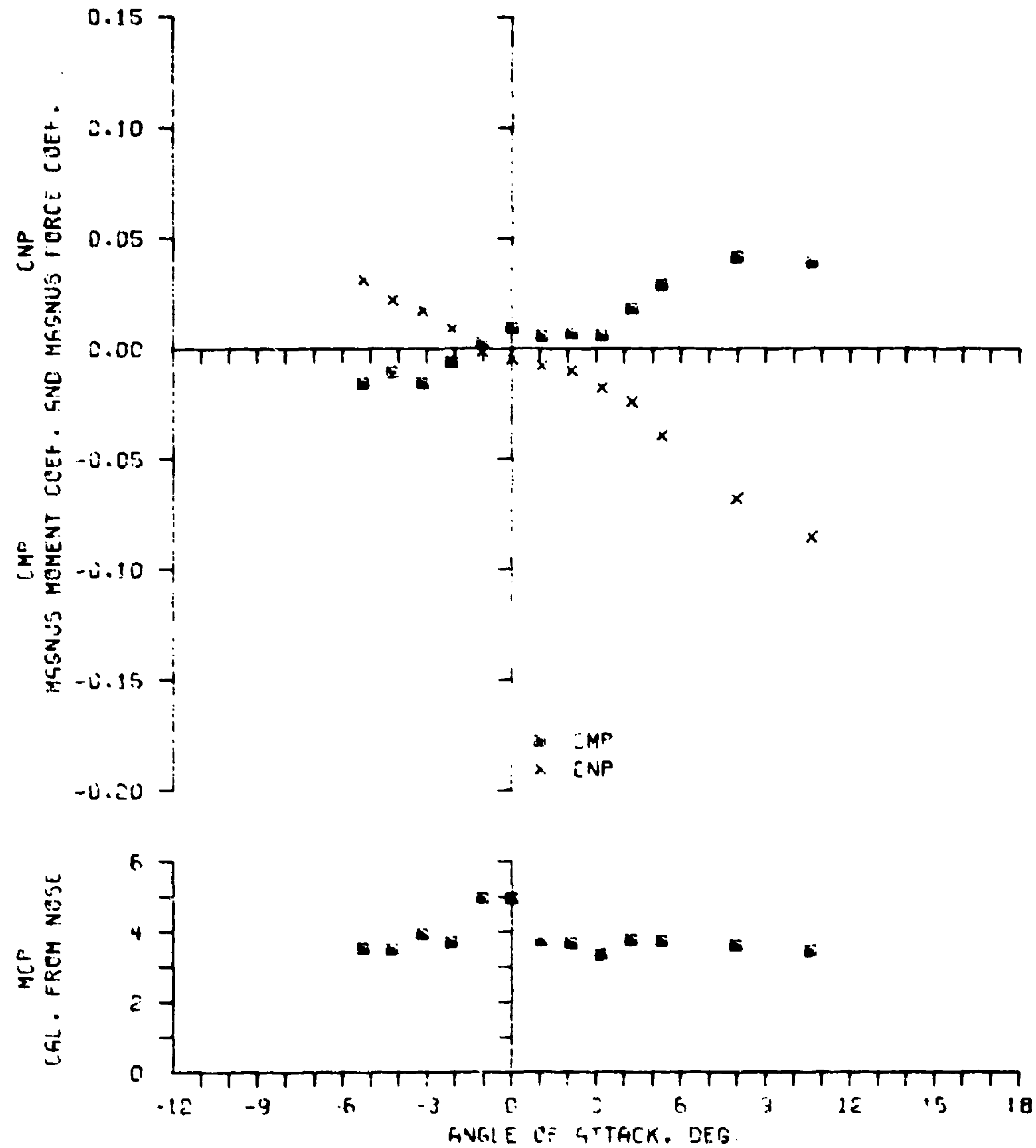
CONFIG= 5.20 RUN= 51.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.70 RE/DIA 1.28 X 10^6



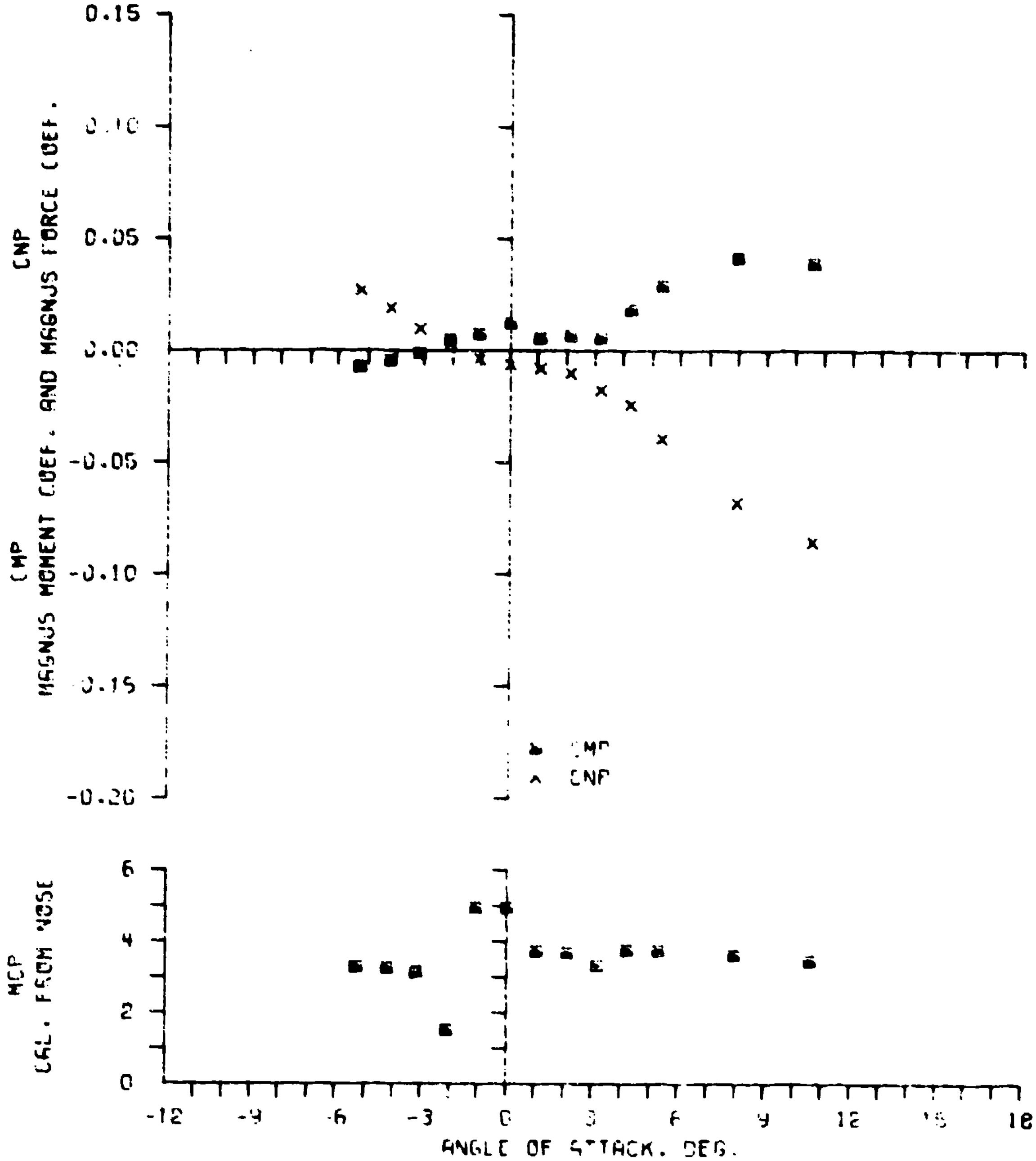
CONFIG= 5.20 RUN= 8.

U.S ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.70 PD/V 0.24 R(DIA) 1.27 X 10^6



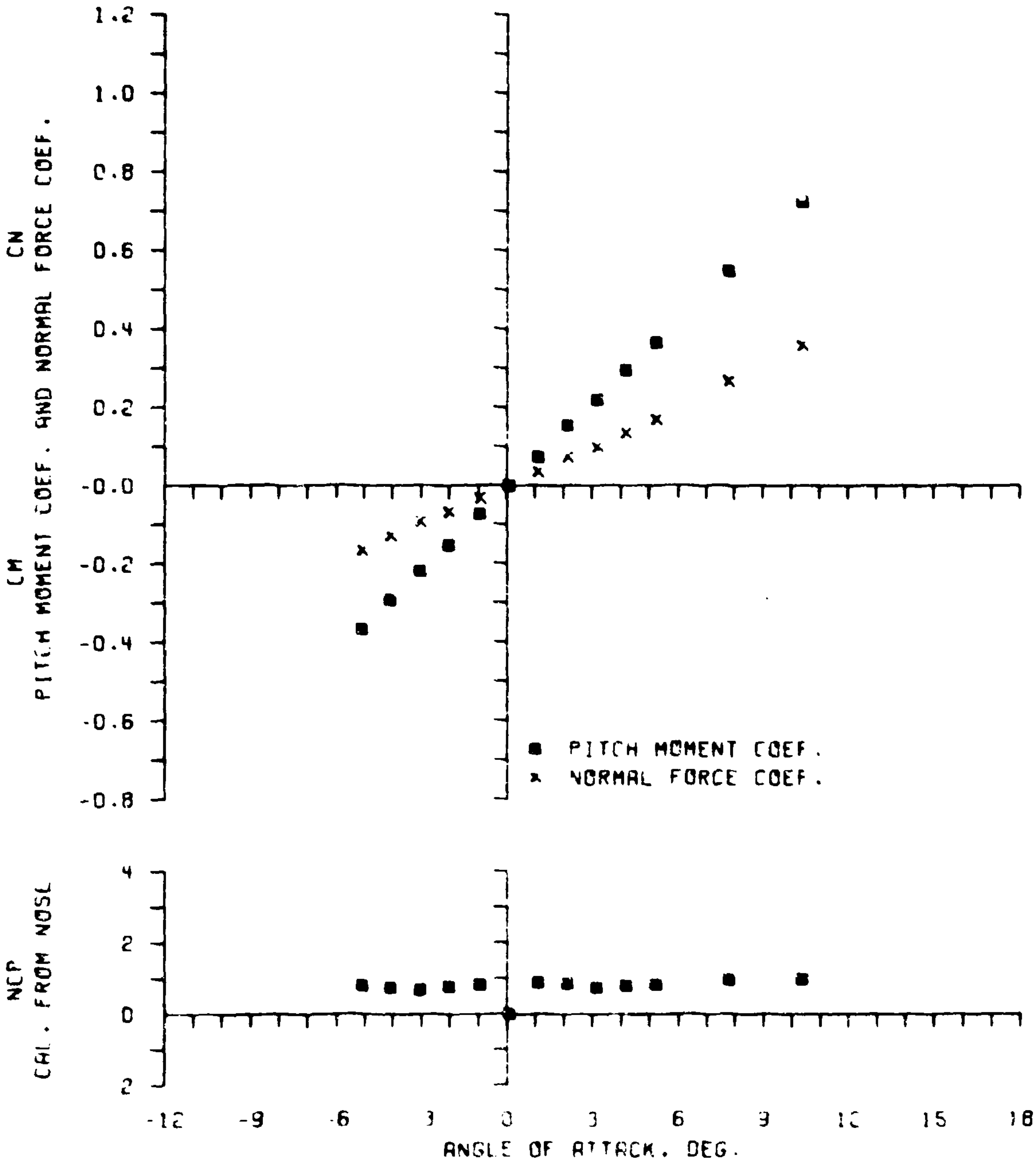
CONFIG= 5.20 RUN= 7.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.70 PD/V 0.48 R(DIA) 1.27 X 10^6



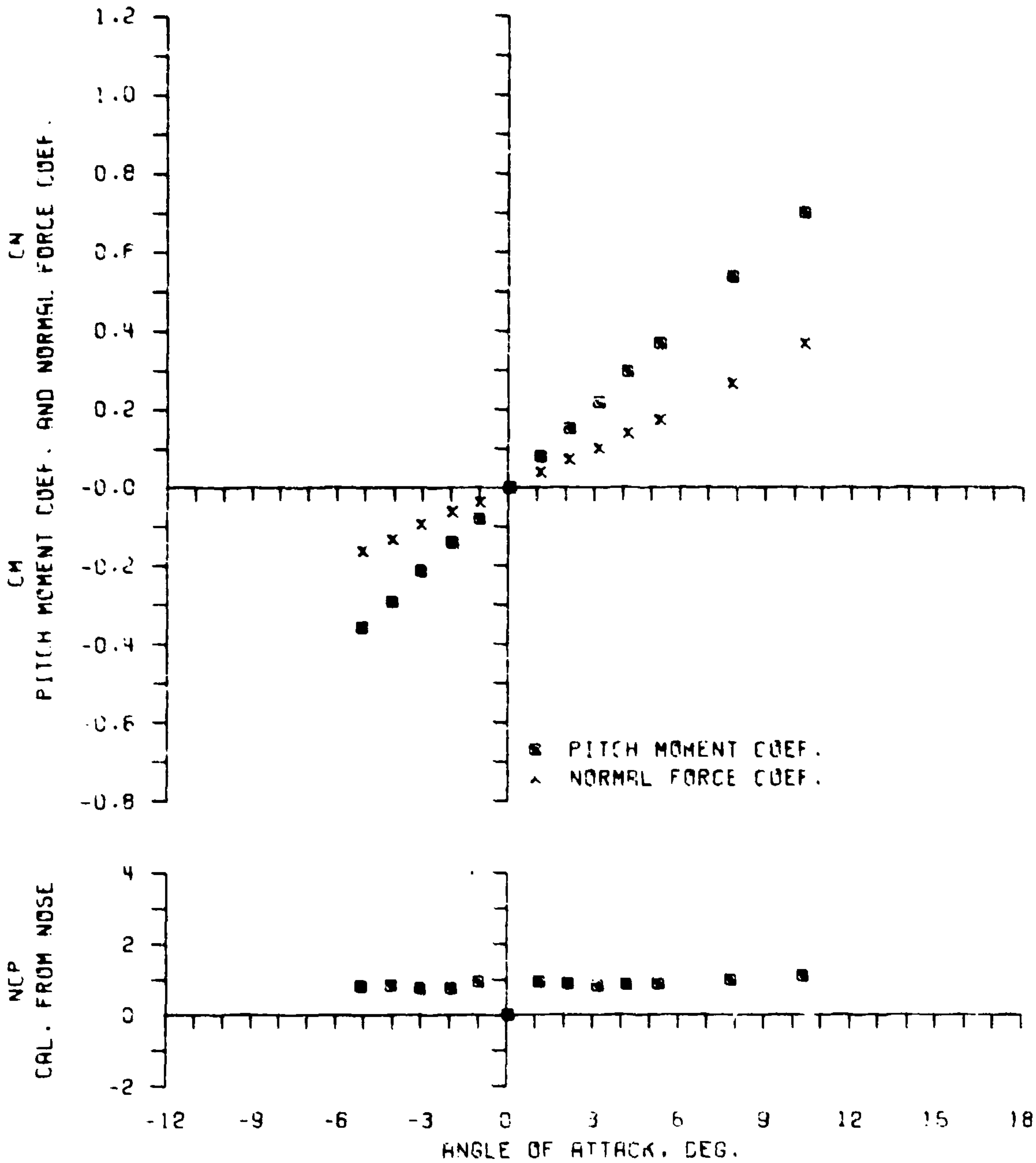
CONFIG= 5.20 RUN= 7.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAIL. STRAIGHT
MACH 0.90 ROLL ZERO DEG. R(DIA) 0.50 X 10^6

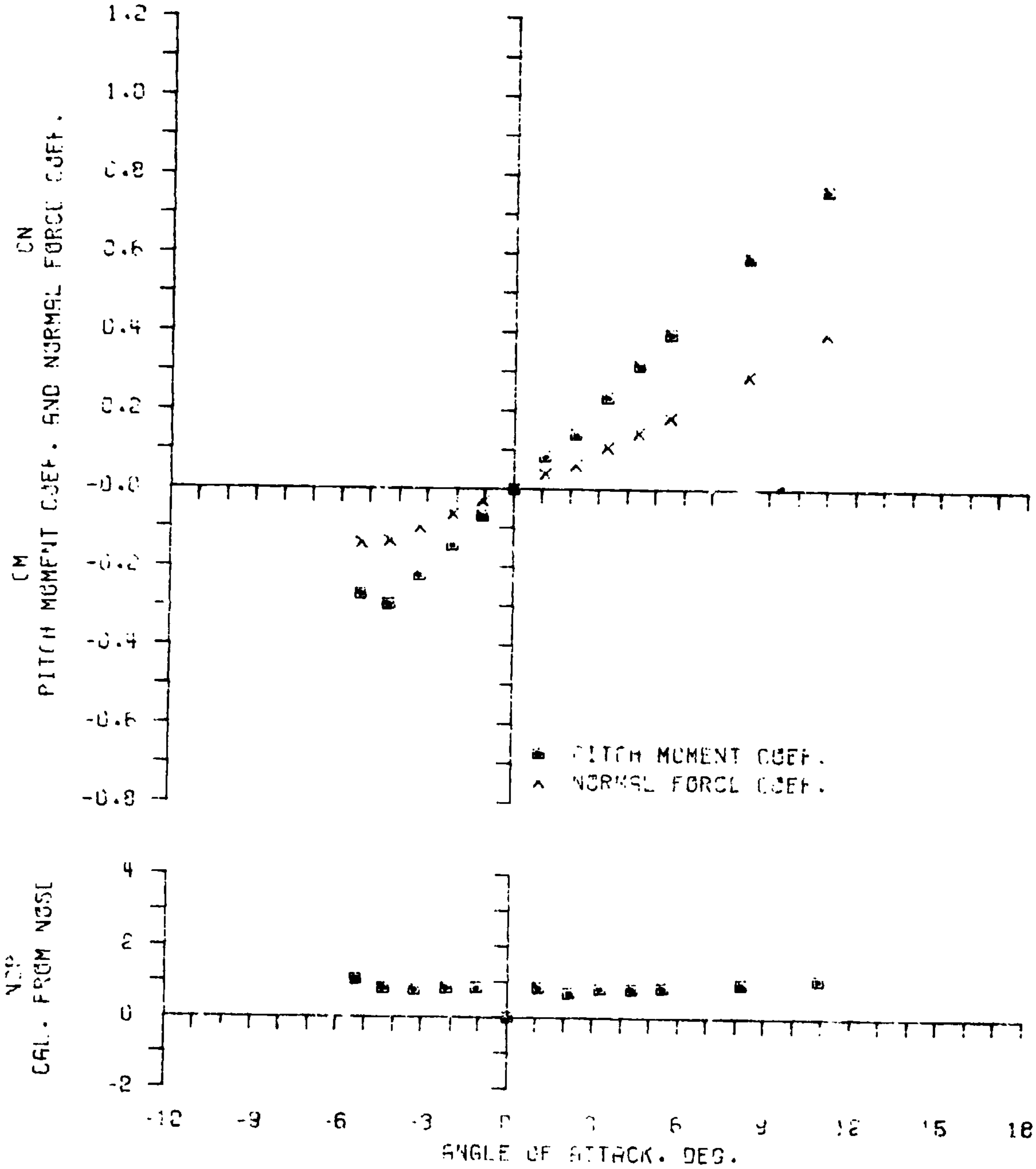


CONFIG= 5.20 RUN= 47.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.90 ROLL 45 DEG. R(DIA) 0.48 X 10^6

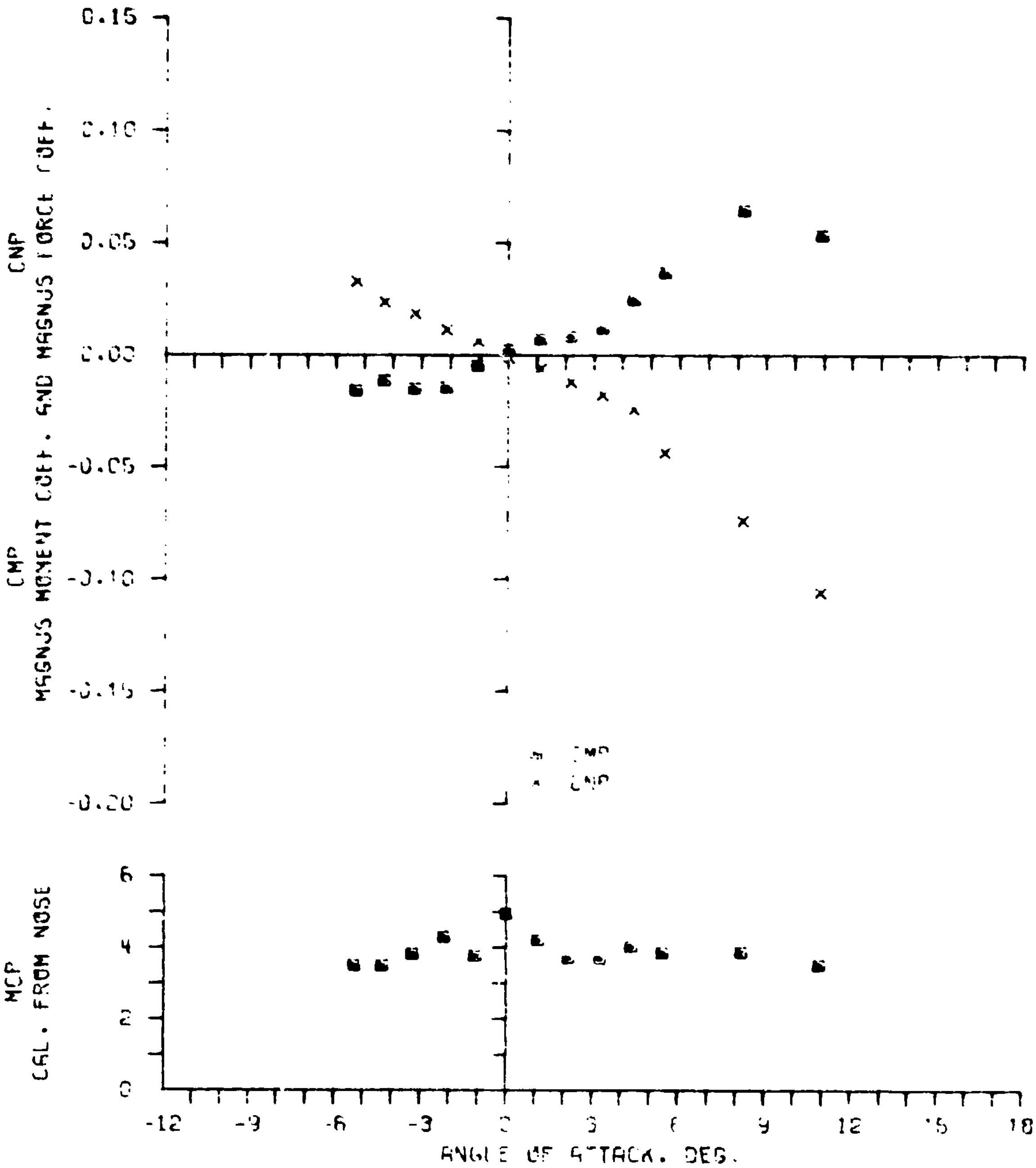


U.S. ARMY BALLISTIC RESEARCH LABORATORY
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.90 R(DIA) 1.42 X 10^6



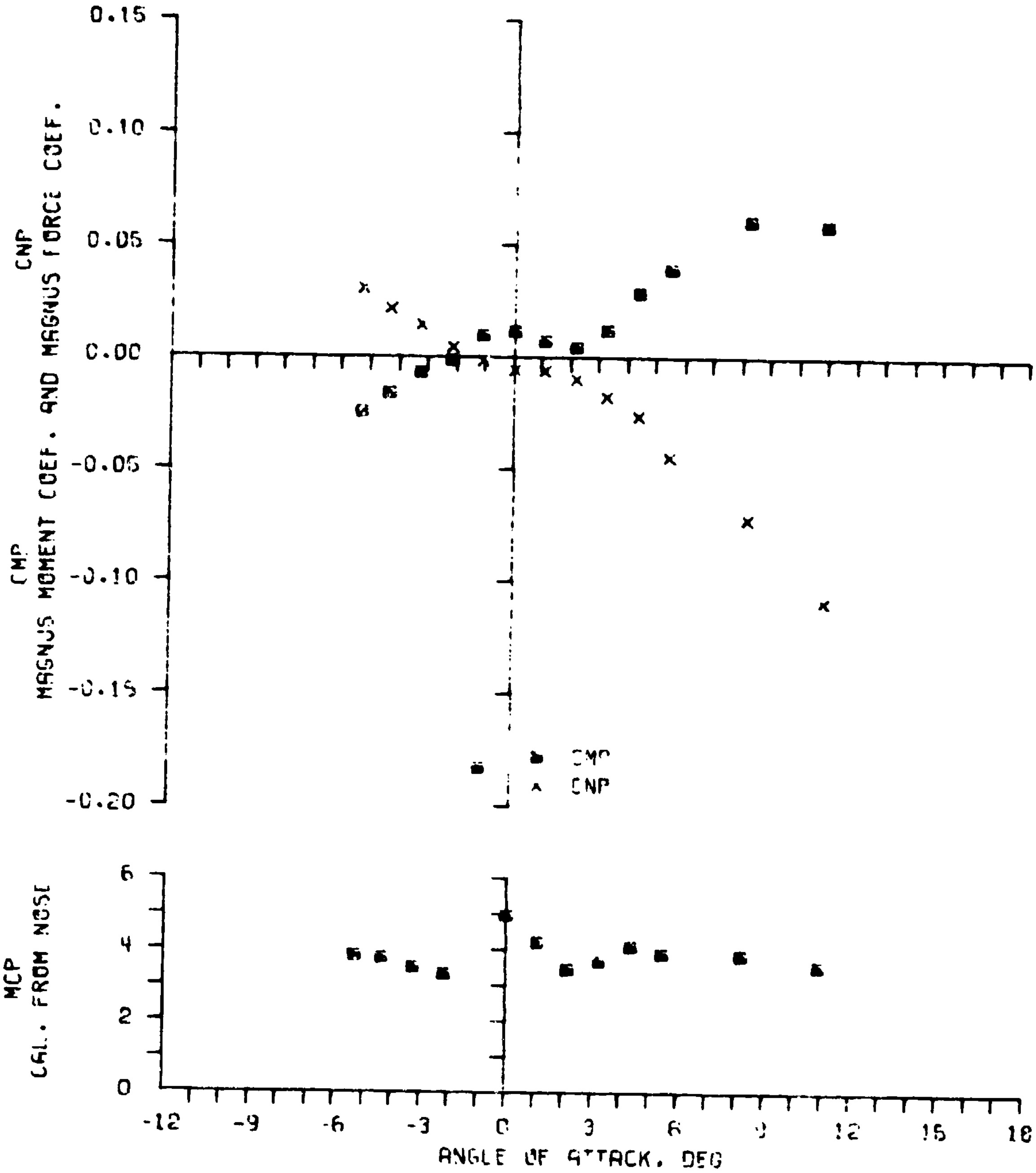
CONFIG= 3.20 RUN= 9.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNEL BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.90 PD/V 0.19 R(DIA) 1.39 X 10^6



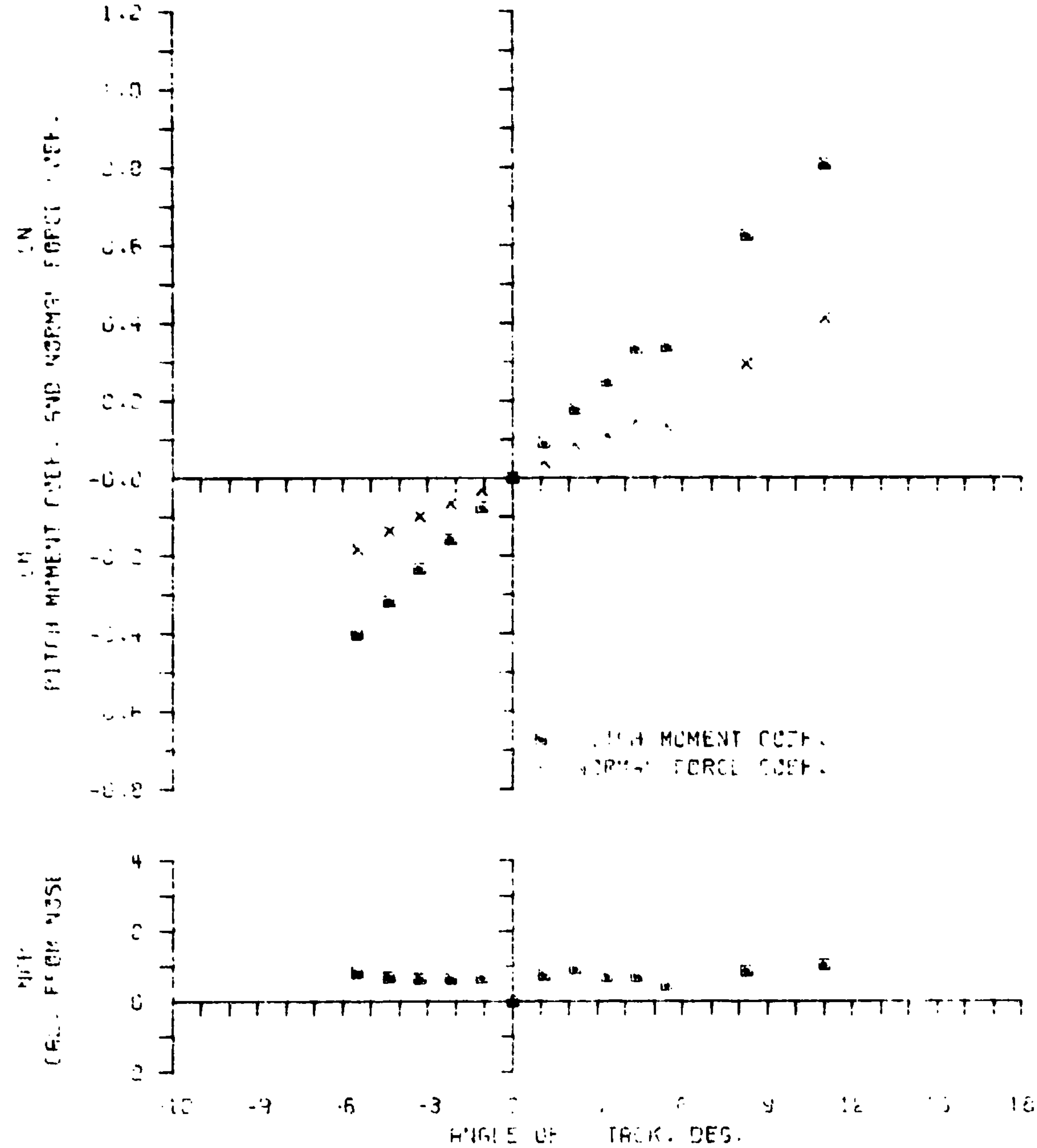
CONFIG= 0.20 RUN= 10.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.90 PD/V 0.38 R(DIA) 1.39 X 10^6



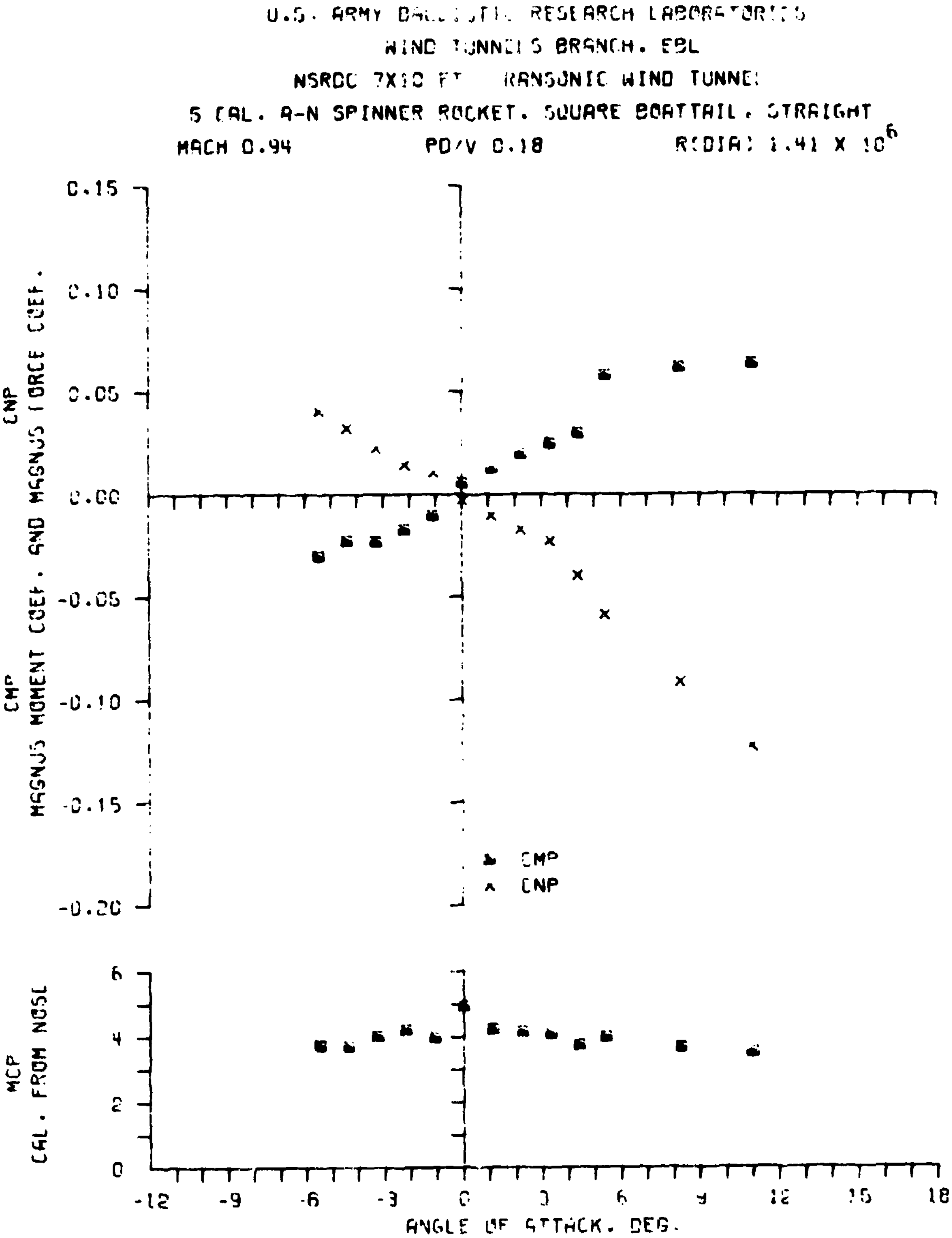
CONFIG= 5.20 RUN= 10

U.S. ARMY [illegible] LABORATORIES
WIND TUNNEL [illegible] BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.94 R/DIA: 1.42 X 10^6



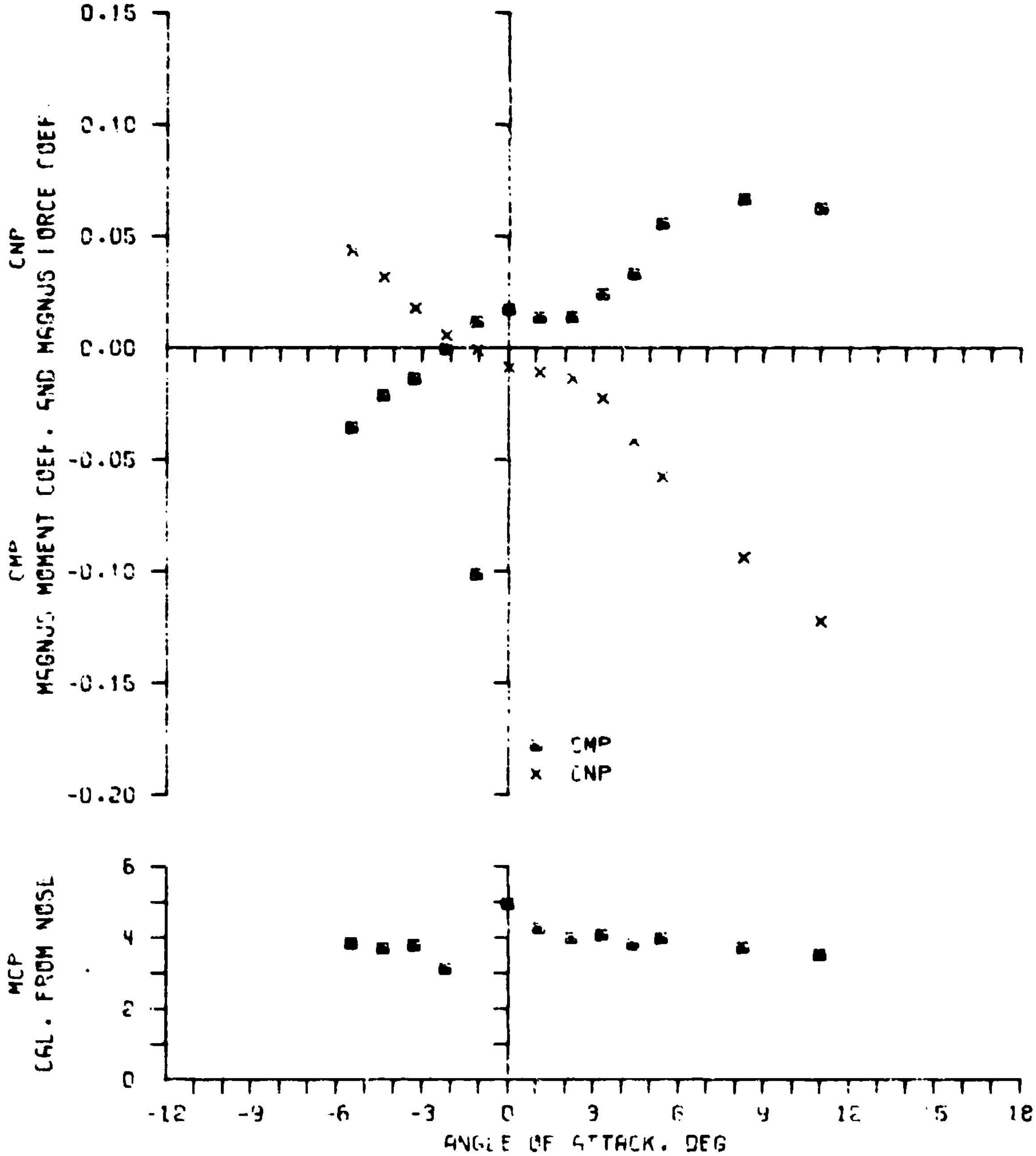
Reproduced from best available copy.

CONFIG= 5.20 RUN= [illegible]



CONFIG= 5.20 RUN= 12

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.94 PD/V 0.36 R(DIA) 1.41 X 10^6



CONFIG= 5.20 RUN= 12

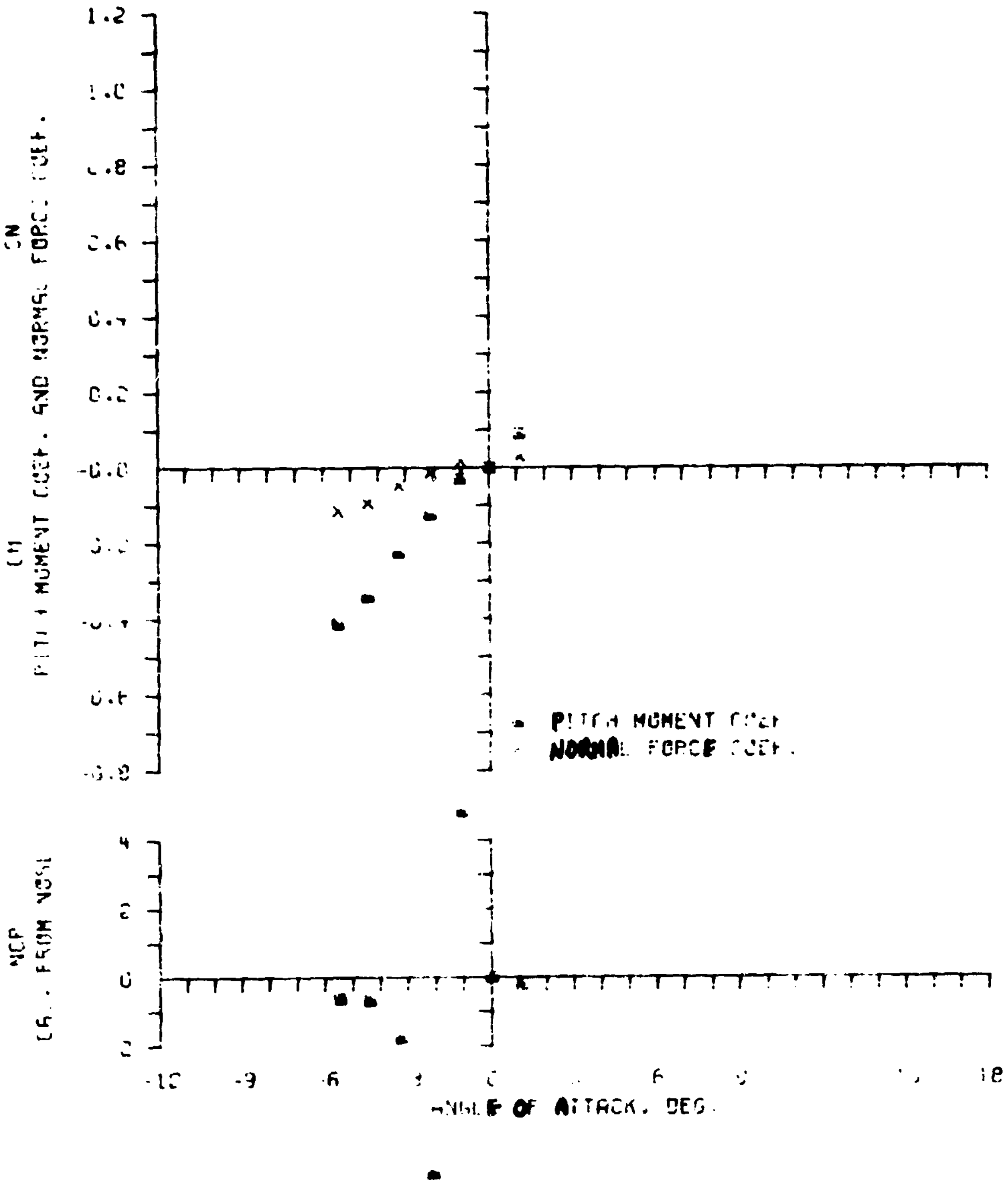
U.S. ARMY BALLISTIC RESEARCH LABORATORIES

WIND TUNNELS BRANCH, EBL

NSRDC 7X10 FT. TRANSONIC WIND TUNNEL

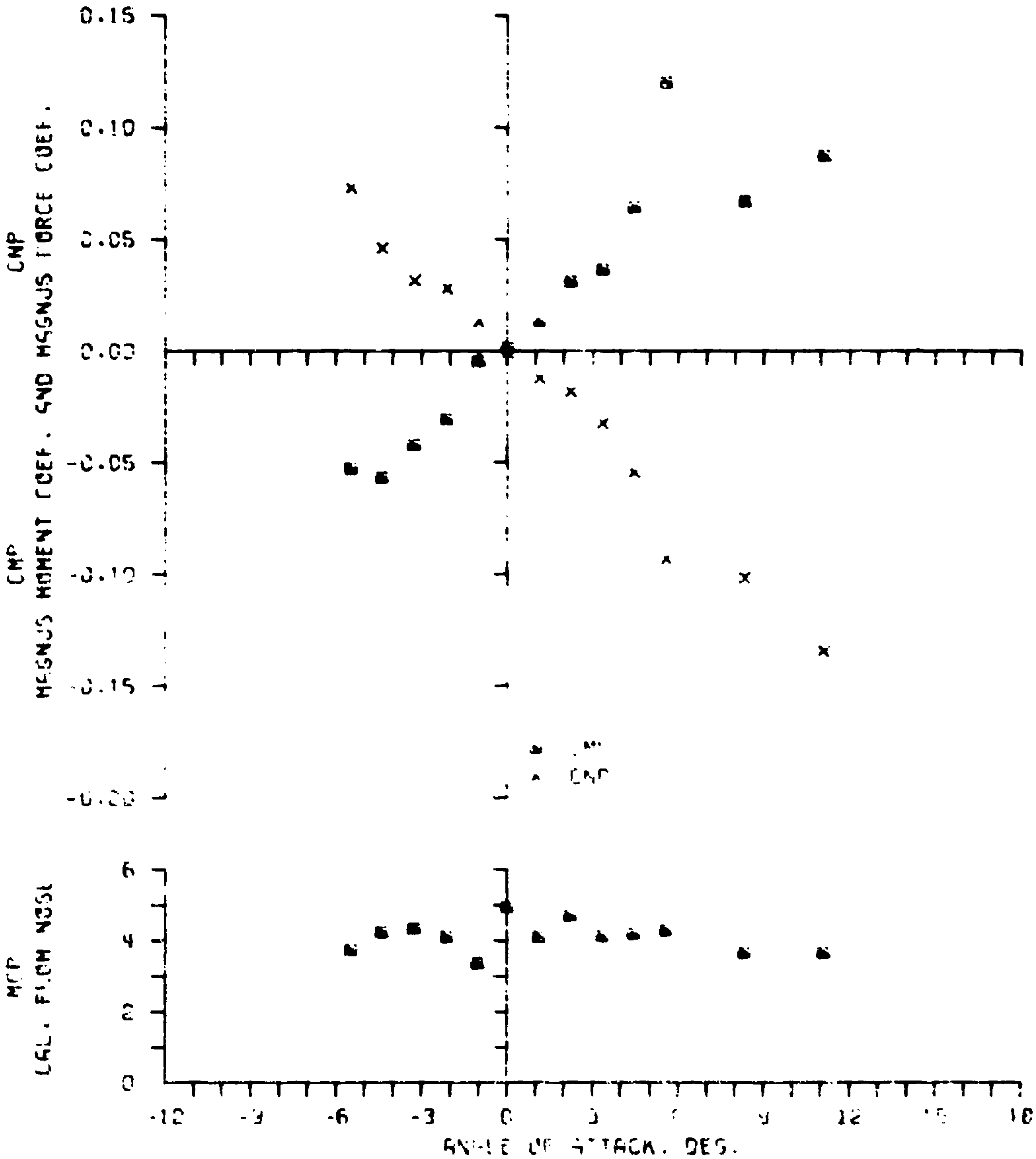
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT

MACH 0.98 RE/DIAM 1.40 X 10^6



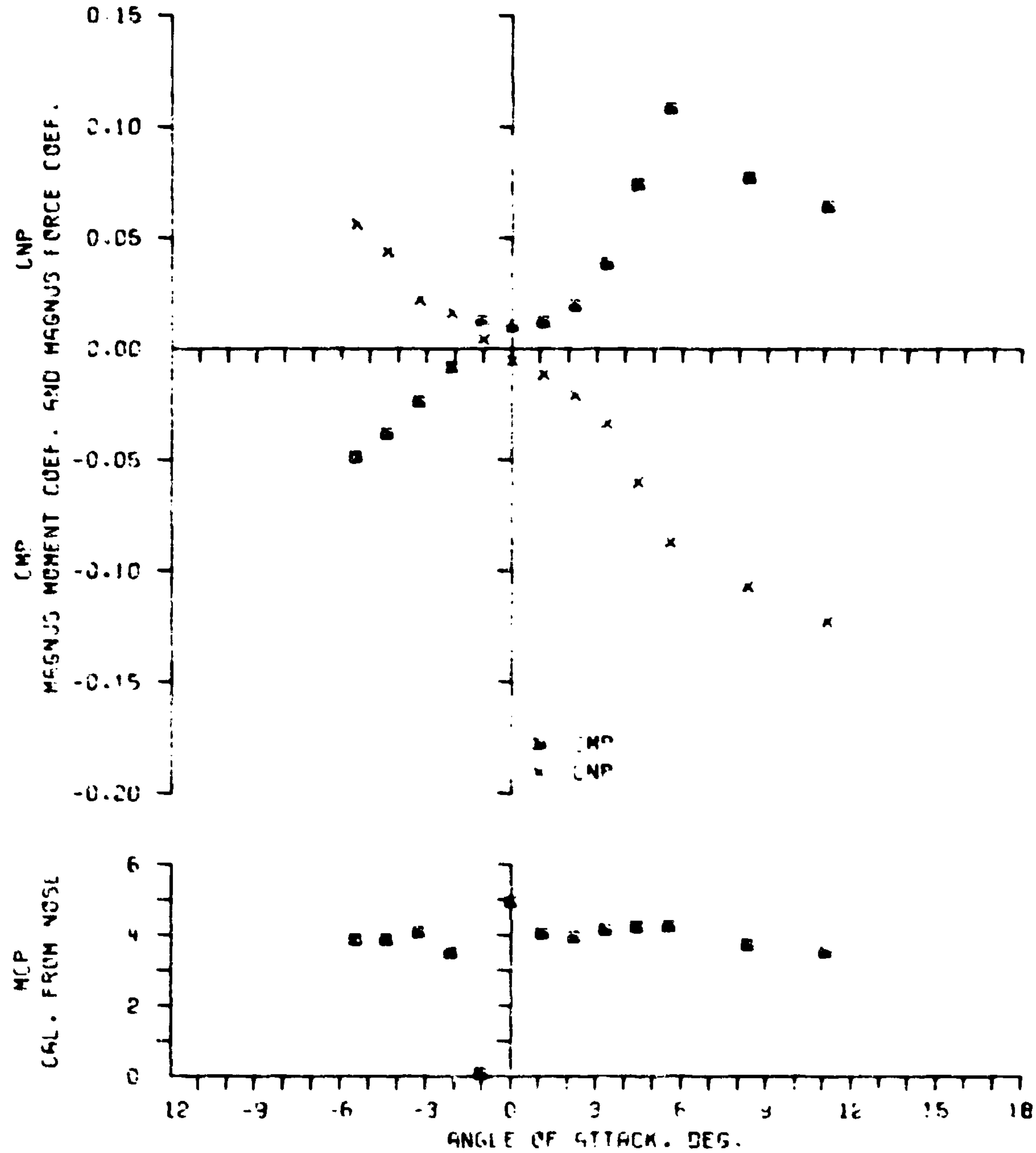
RUN: 10 - 5-20 RUN= 14.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.99   PD/V 0.17   R/DIA 1.42 X 10^6



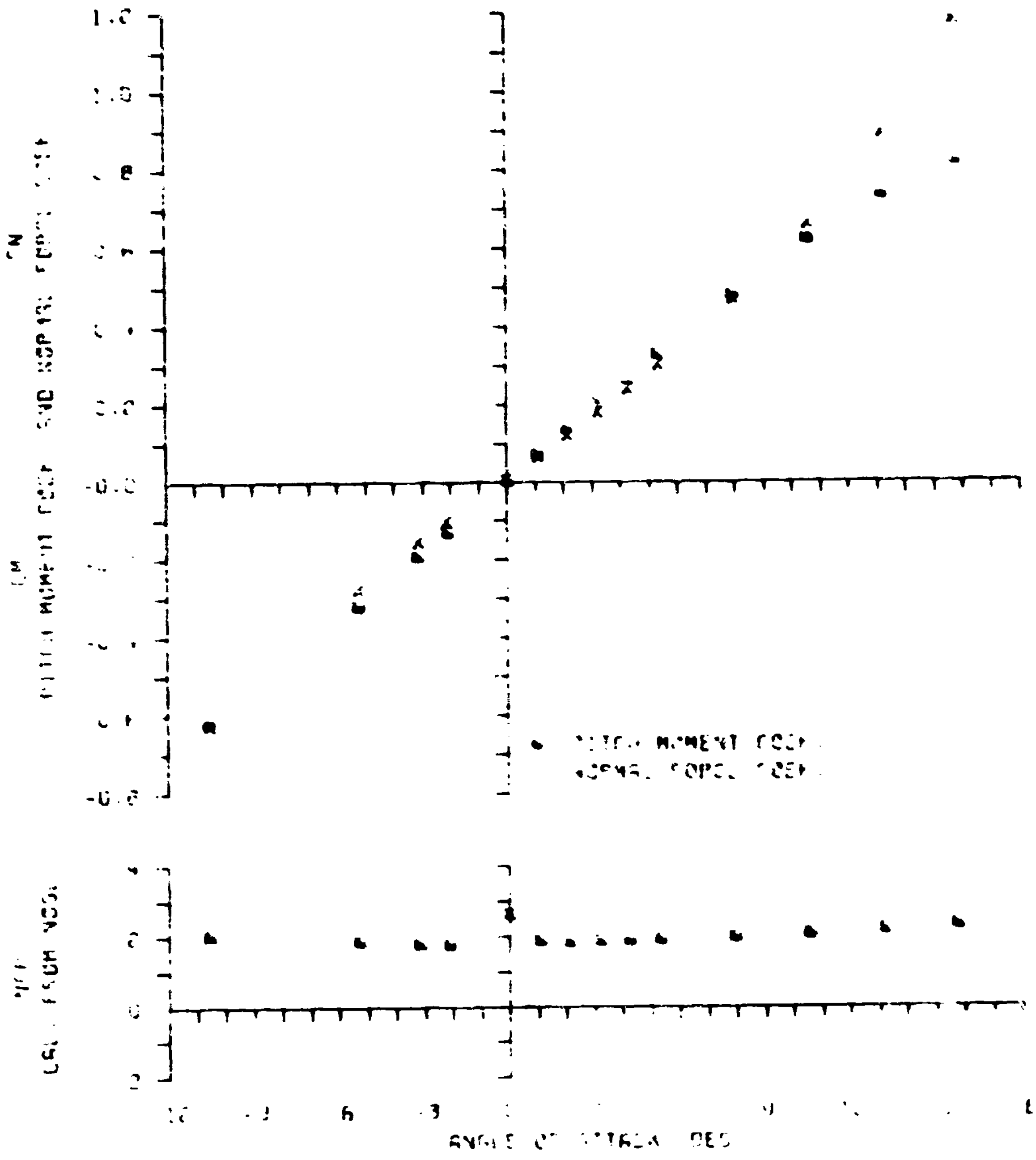
CONFIG= 5.20 RUN= 13

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 0.98 PD/V 0.35 R/DIA) 1.42 X 10^6



CONFIG= 5.20 RUN= 13.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 1.75 RADIAL 0.92 X 10



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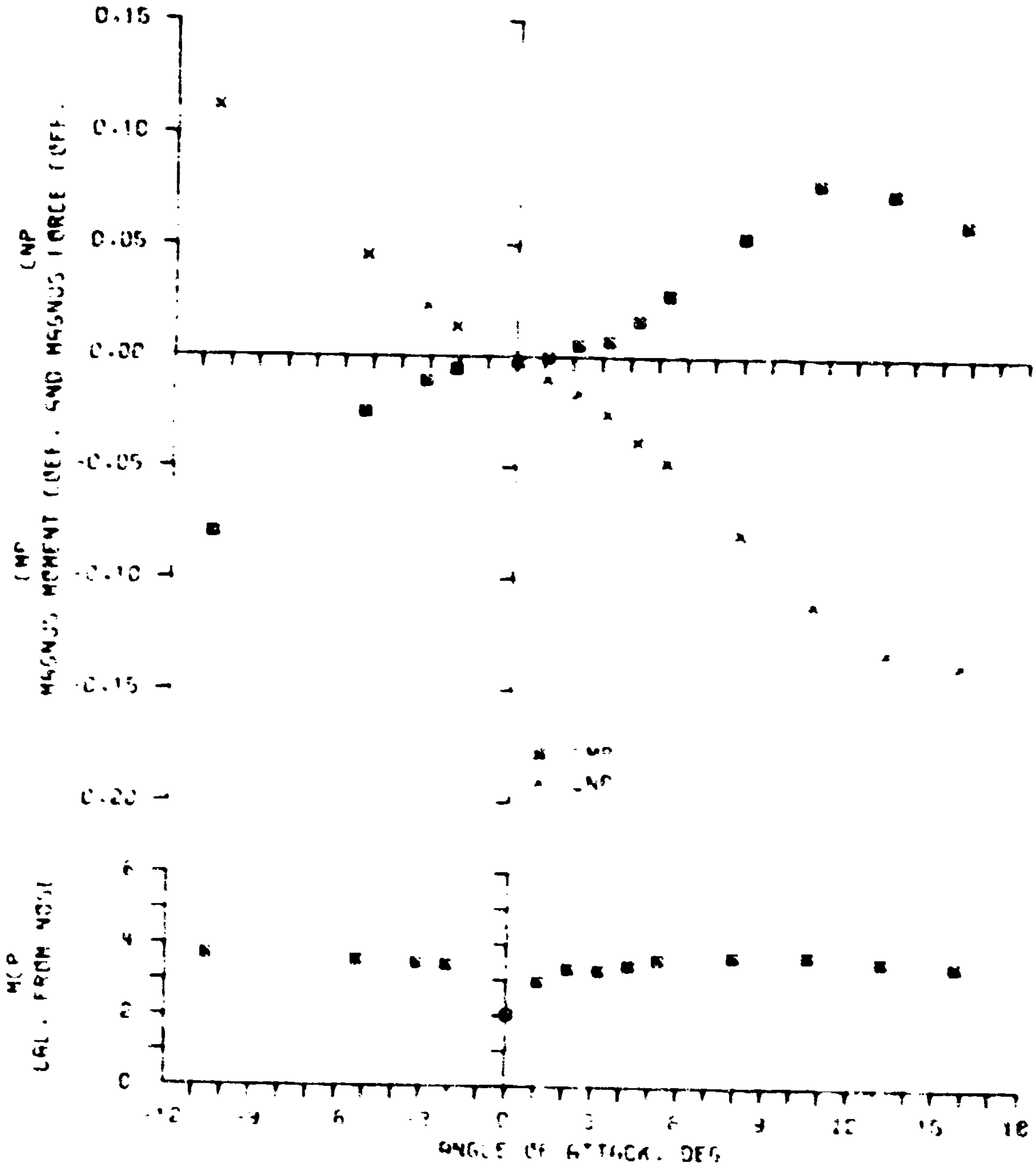
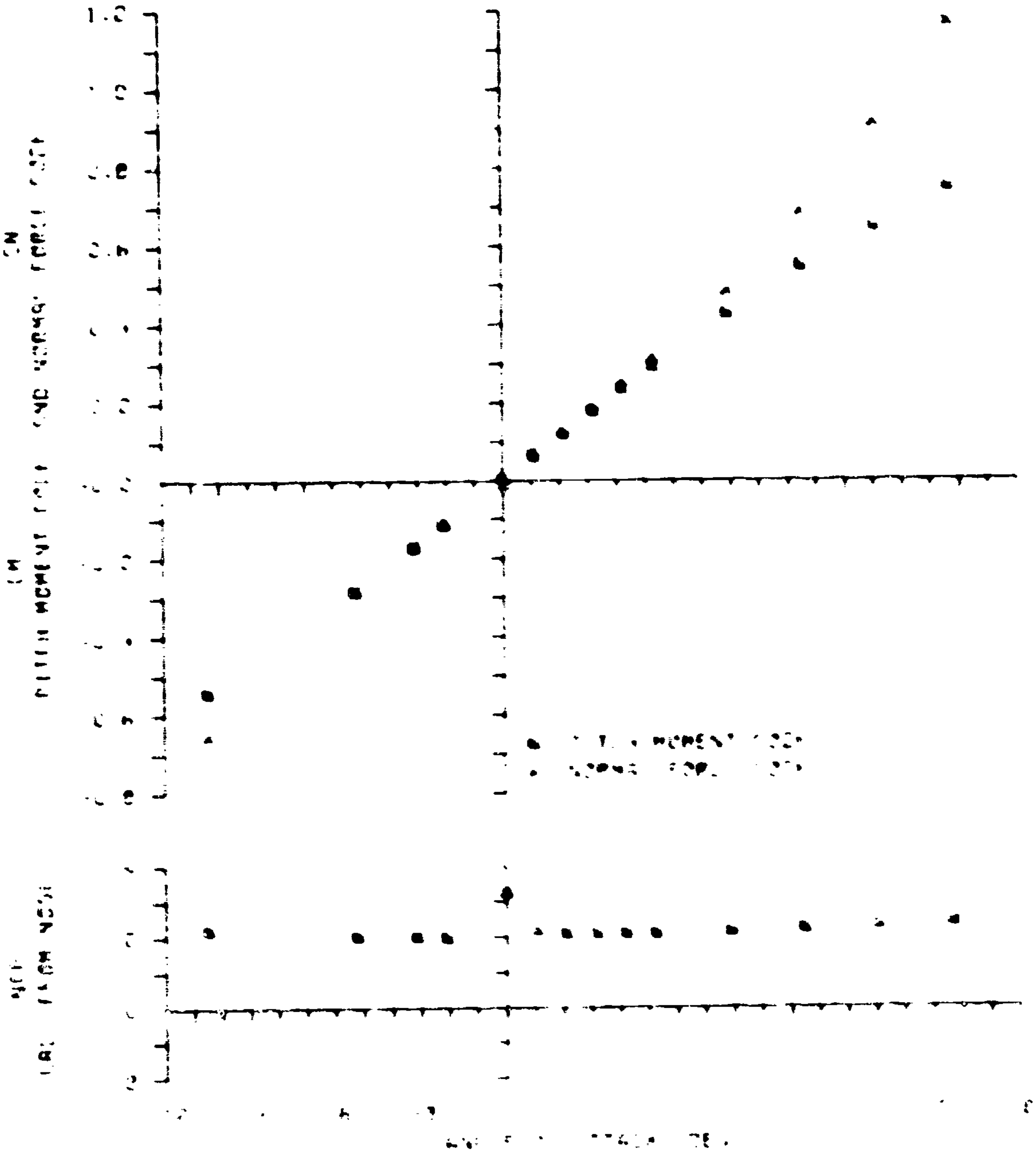
CONFIG= 5.20 RUN= 10.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 1.75 PD/V 0.33 R/DIA 0.92 X 10^6



CONFIG= 5-20 RUN= 10.

U.S. ARMY B... LABORATORIES
WIND TUNNEL ...
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT
MACH 2.50 ... X 10^6



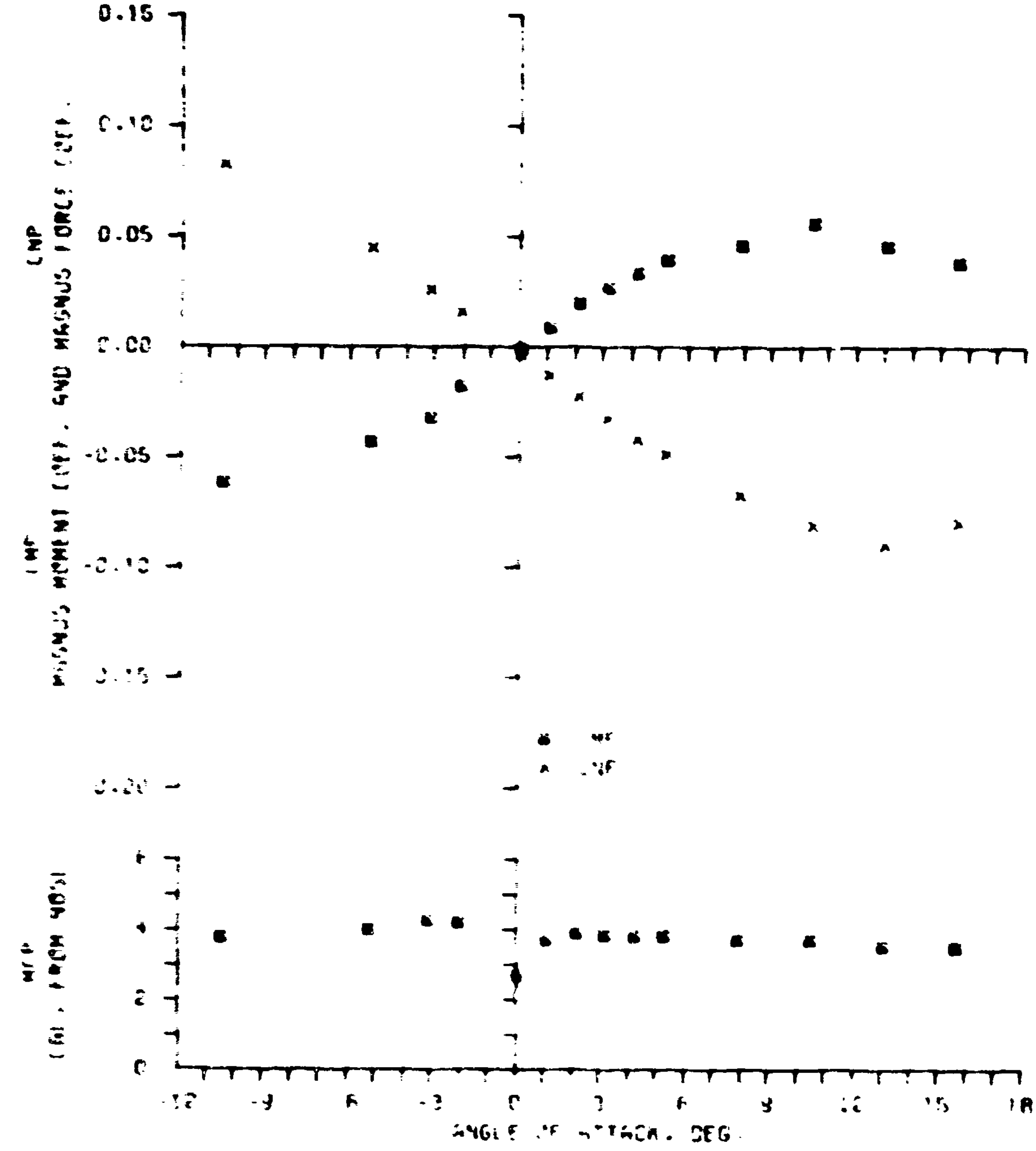
PONTIUS 5 ... RUNS

U.S. ARMY BALLISTIC RESEARCH LABORATORIES

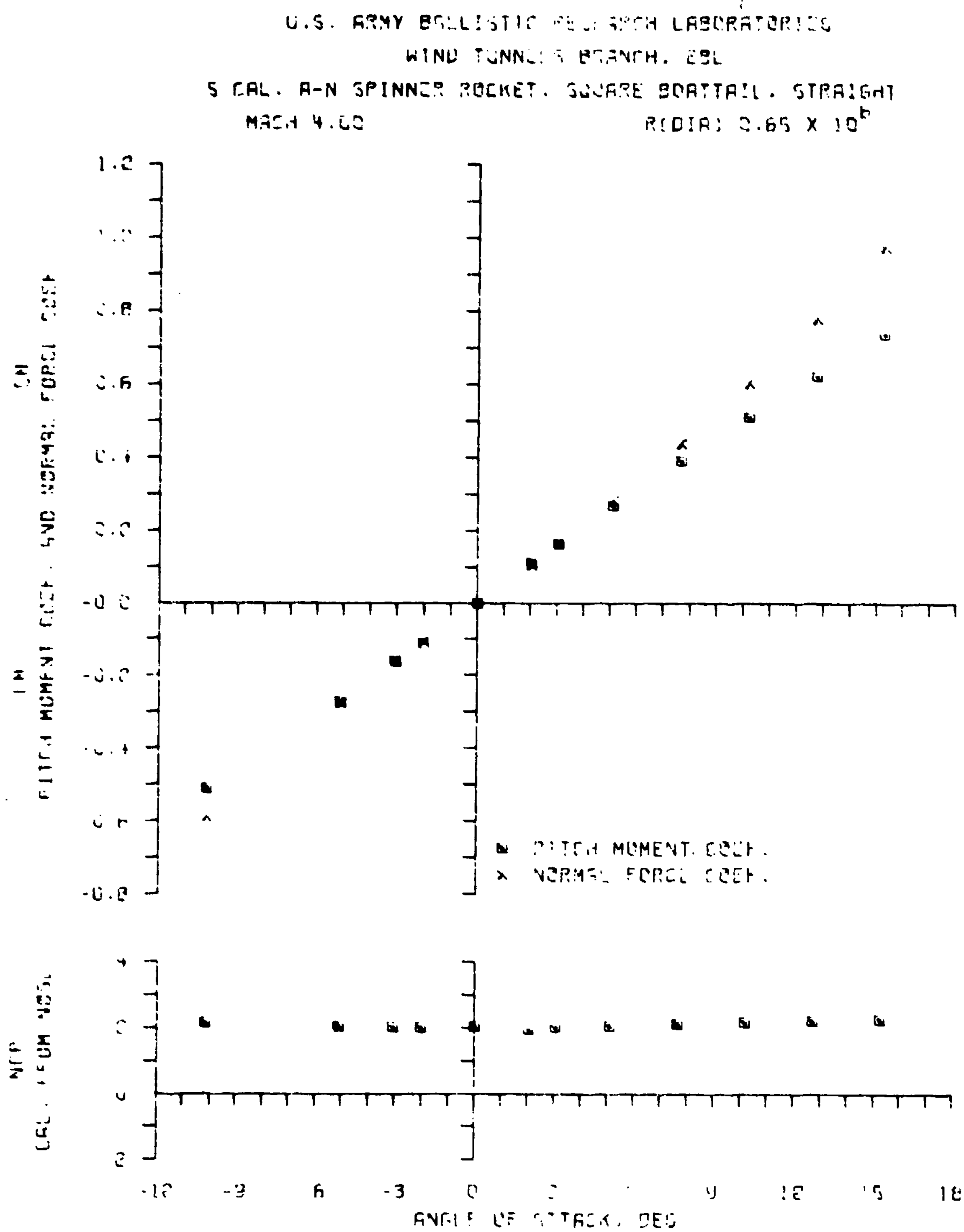
WIND TUNNELS BRANCH, EBL

5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, STRAIGHT

MACH 2.50 PD/V 0.25 R/DIA 0.94 X 10^6

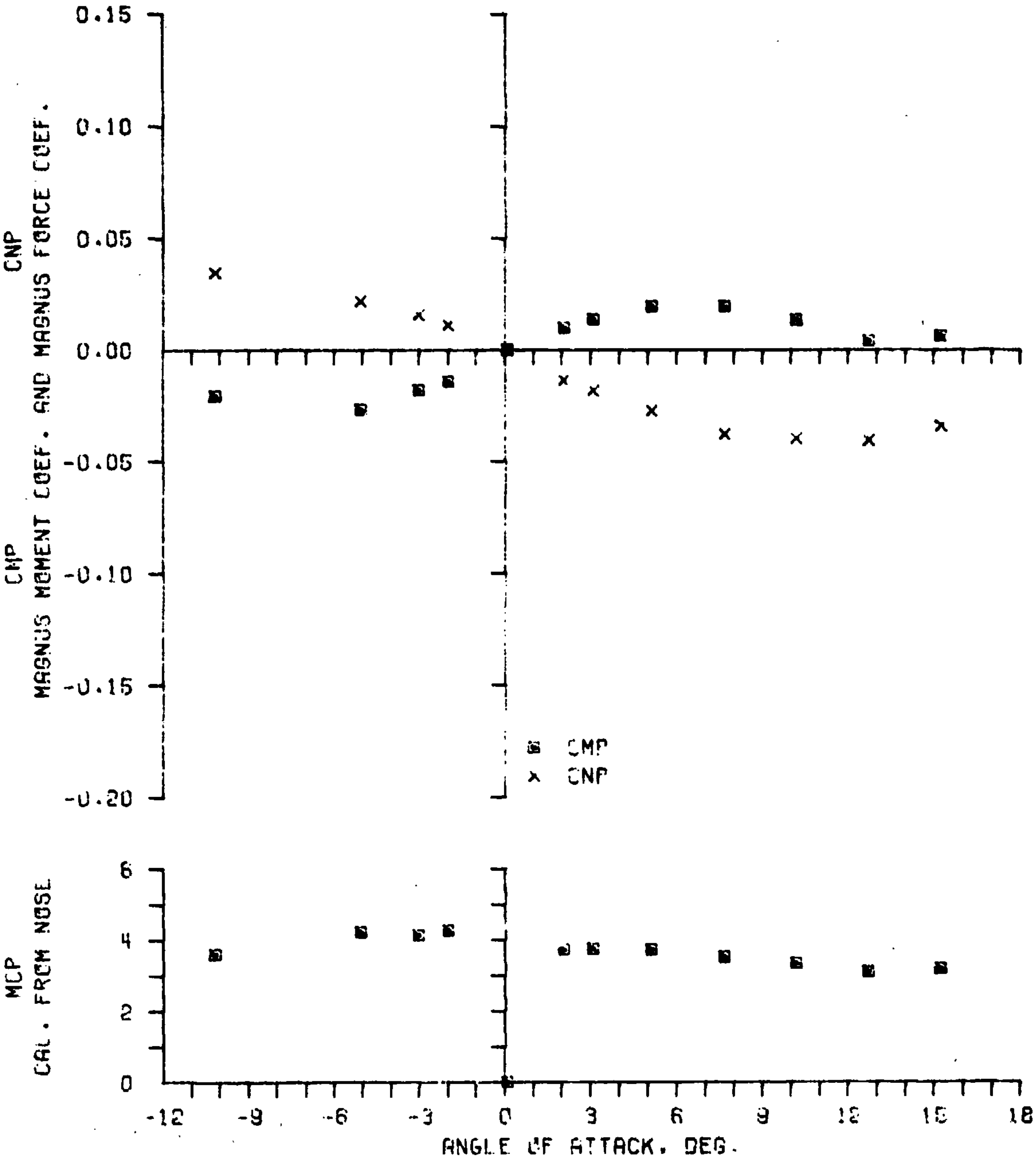


CONFIG: 0.20 RUN: 11



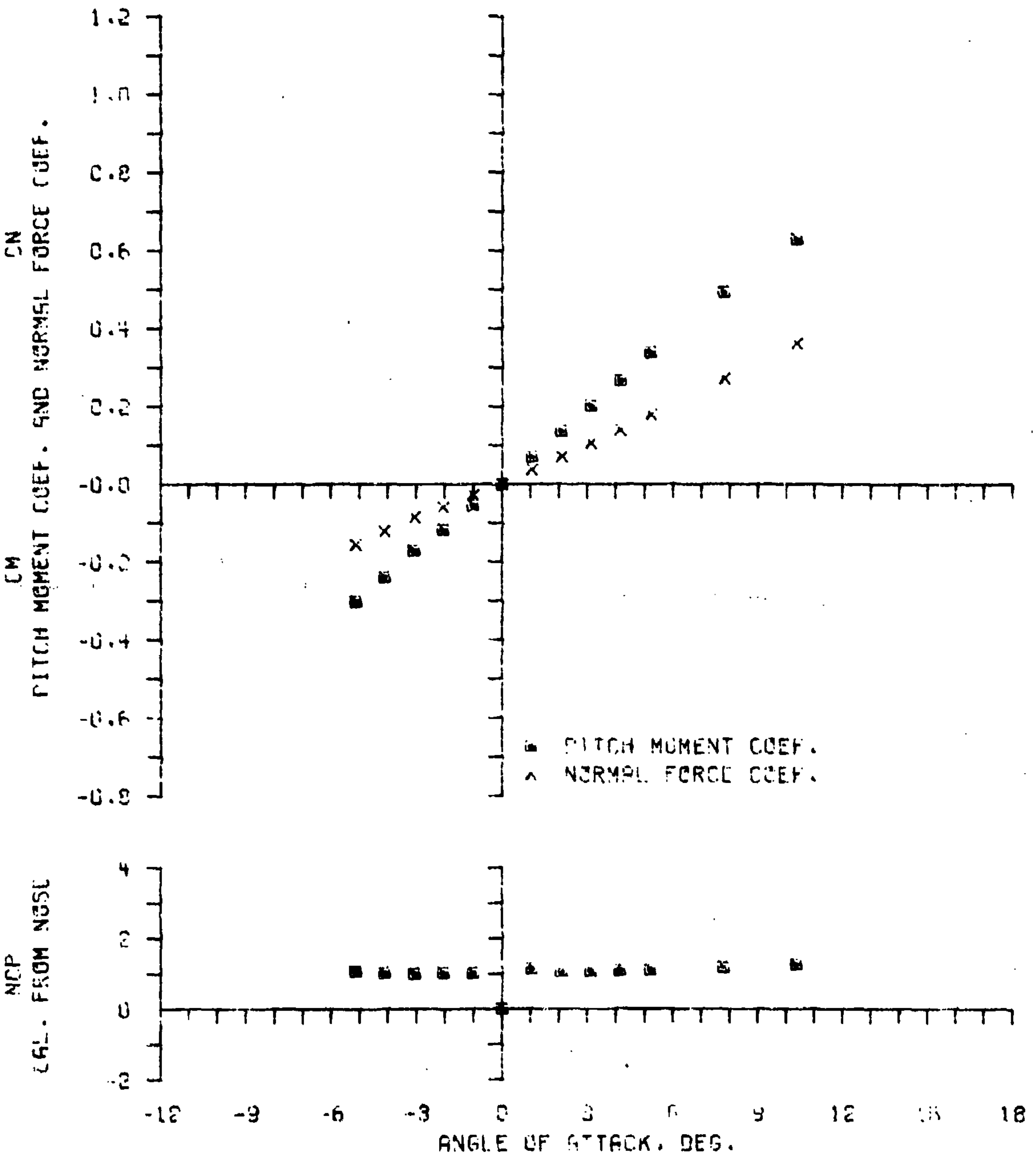
CONFIG 5.00 RUN= 12

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH. EBL
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAIL. STRAIGHT
MACH 4.00 PD/V 0.24 R(DIA) 0.65 X 10^6

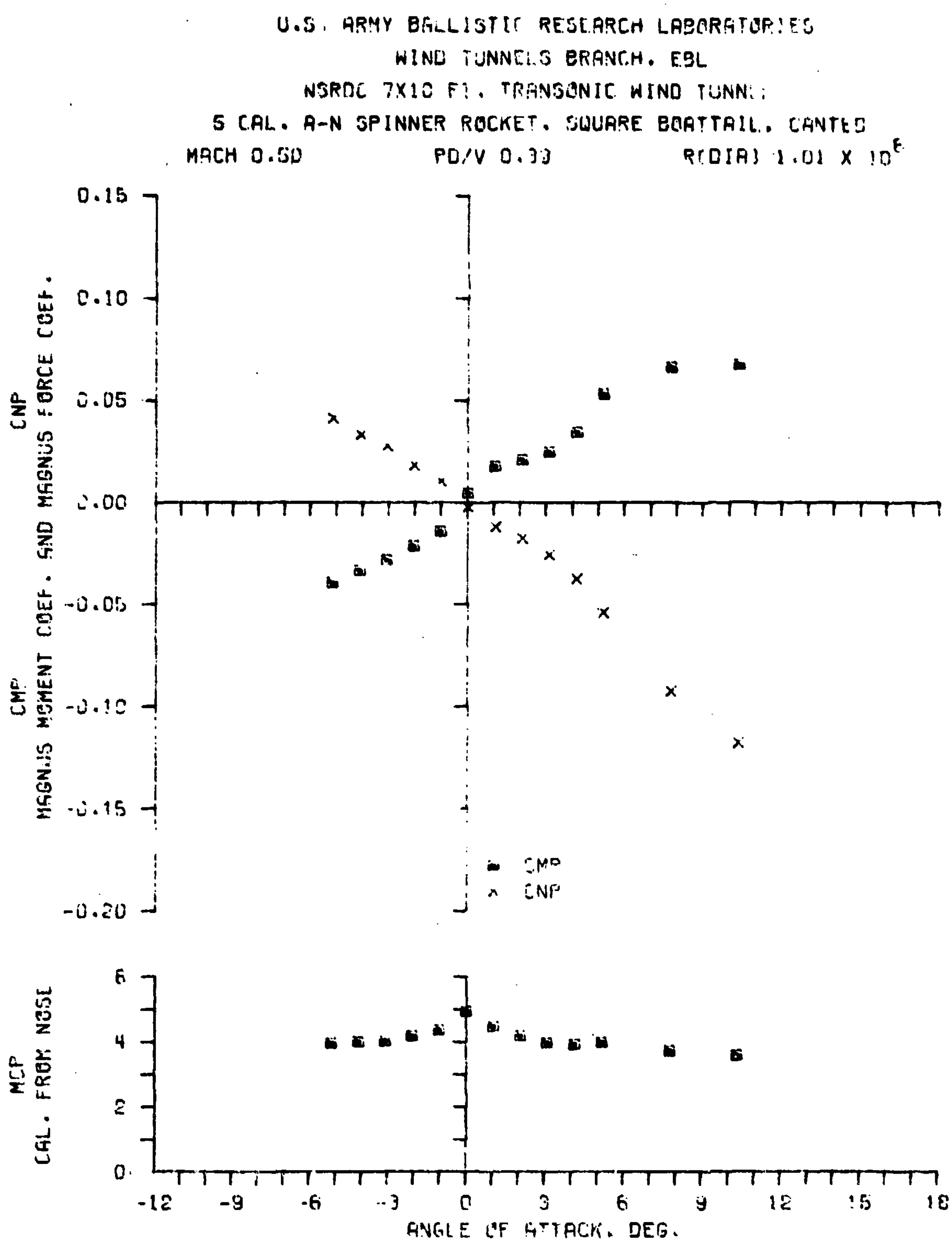


CONFIG= 5.20 RUN= 12.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.50 R(DIA) 1.04 X 10^6



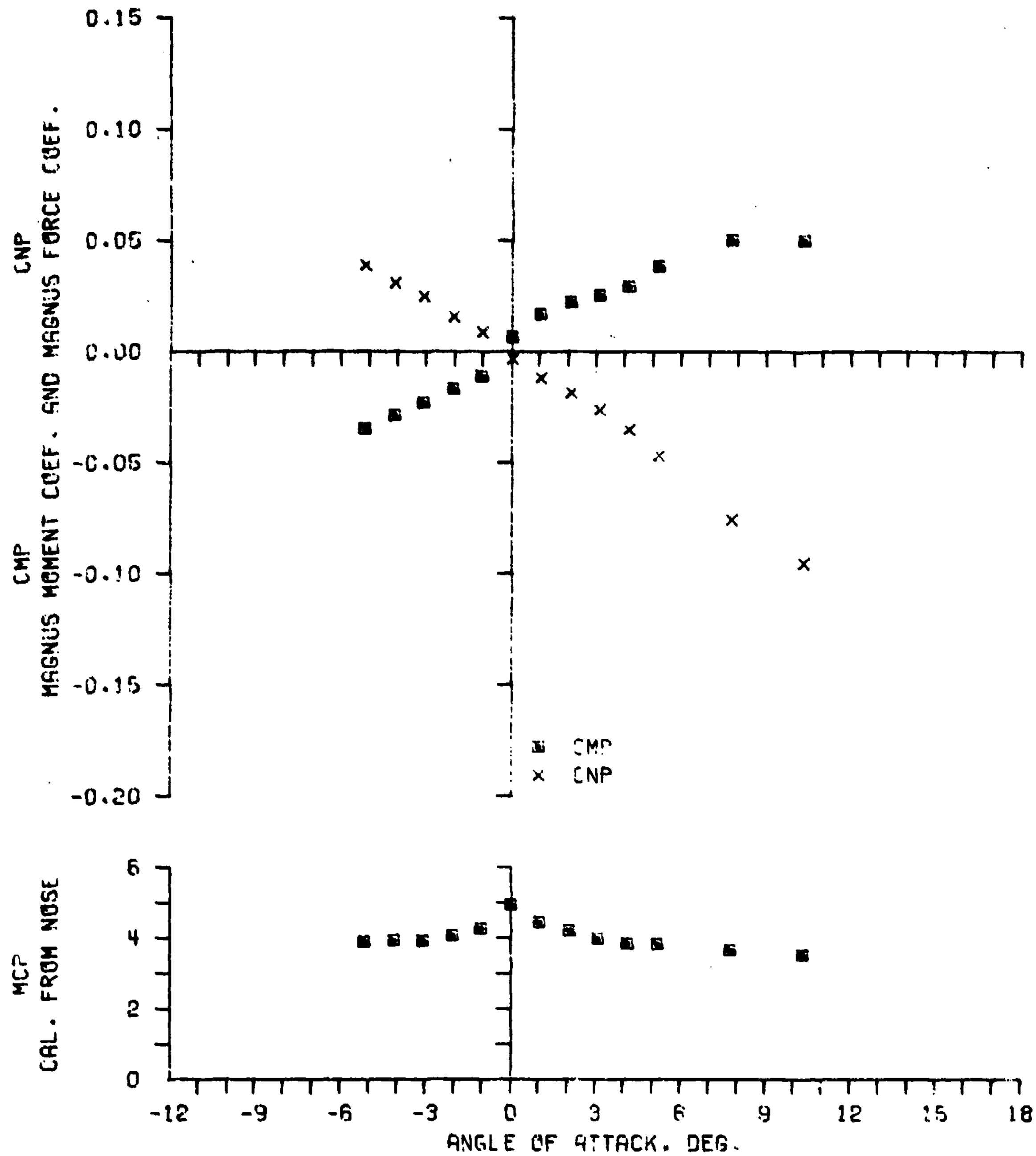
CONFIG= 5.30 RUN= 18.



ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG= 5.30 RUN= 17.

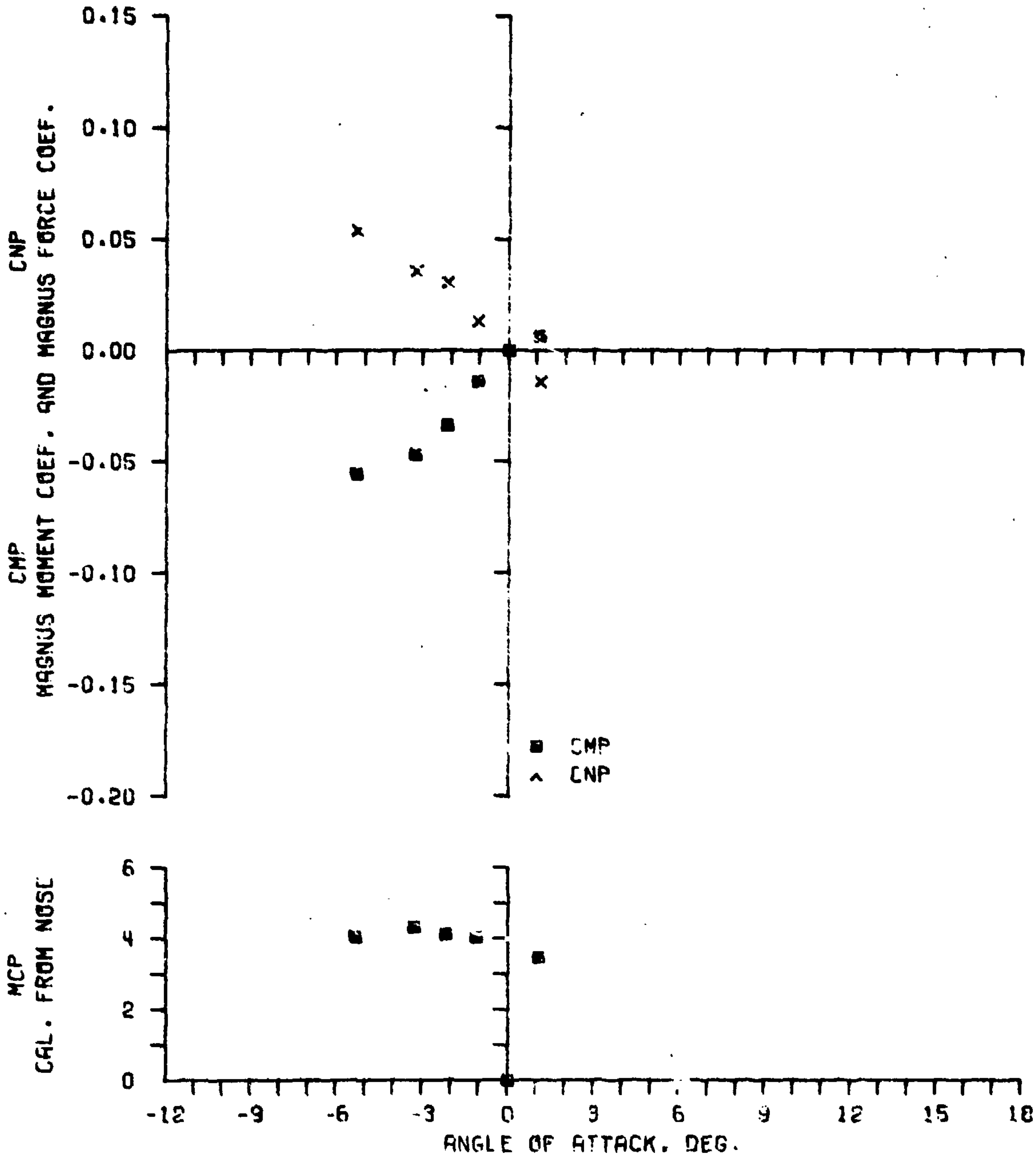
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.50 PD/V 0.66 R(DIA) 1.01 X 10^6



ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG= 5.30 RUN= 17.

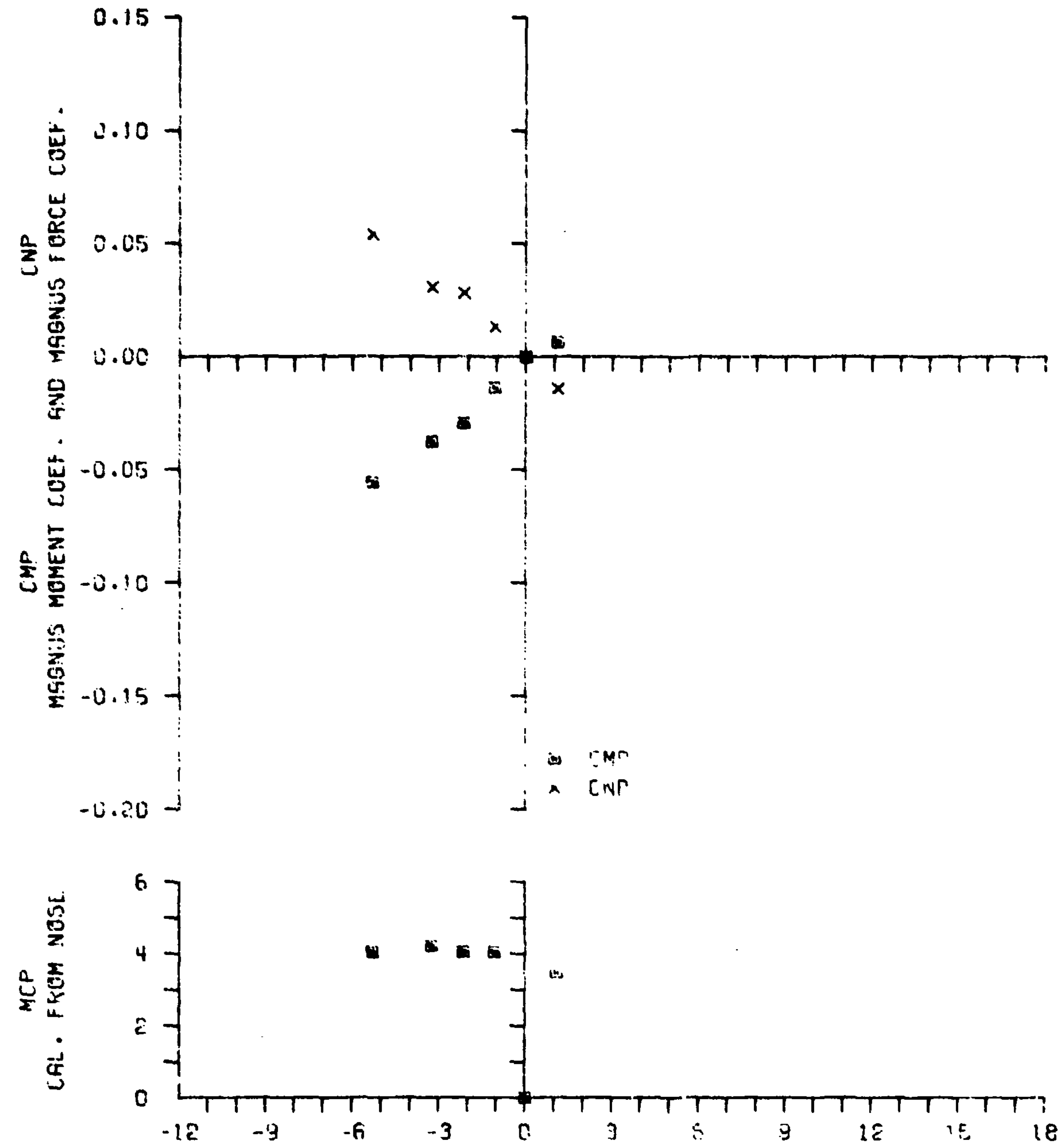
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.90 PD/V 0.19 R(DIA) 1.39 X 10^6



ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG= 5.30 RUN= 19.

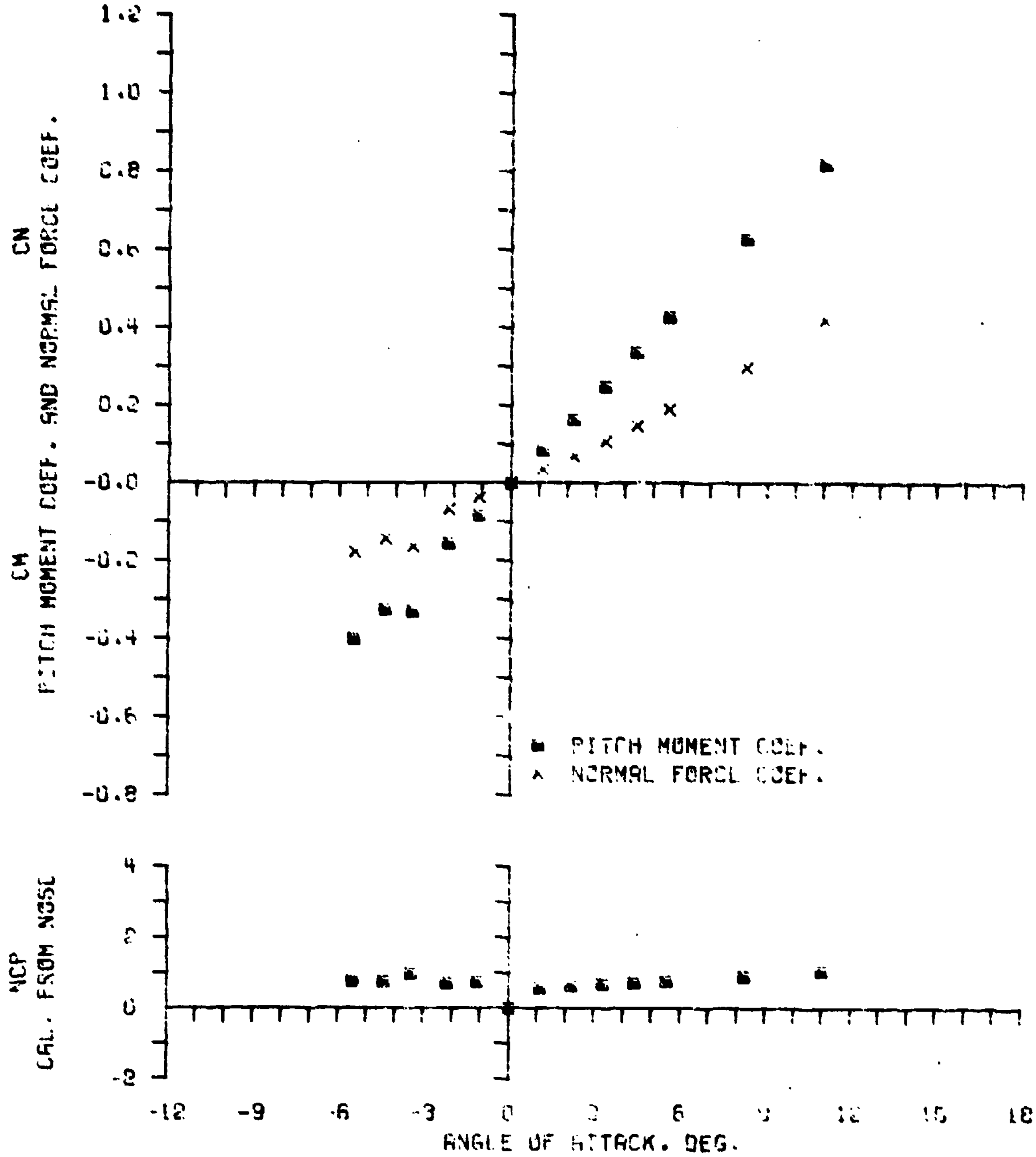
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.90 PD/V 0.38 R(DIA) 1.39 X 10^6



ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

†CONFIG= 5.30 RUN= 19.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.94 R(DIA) 1.43 X 10^6

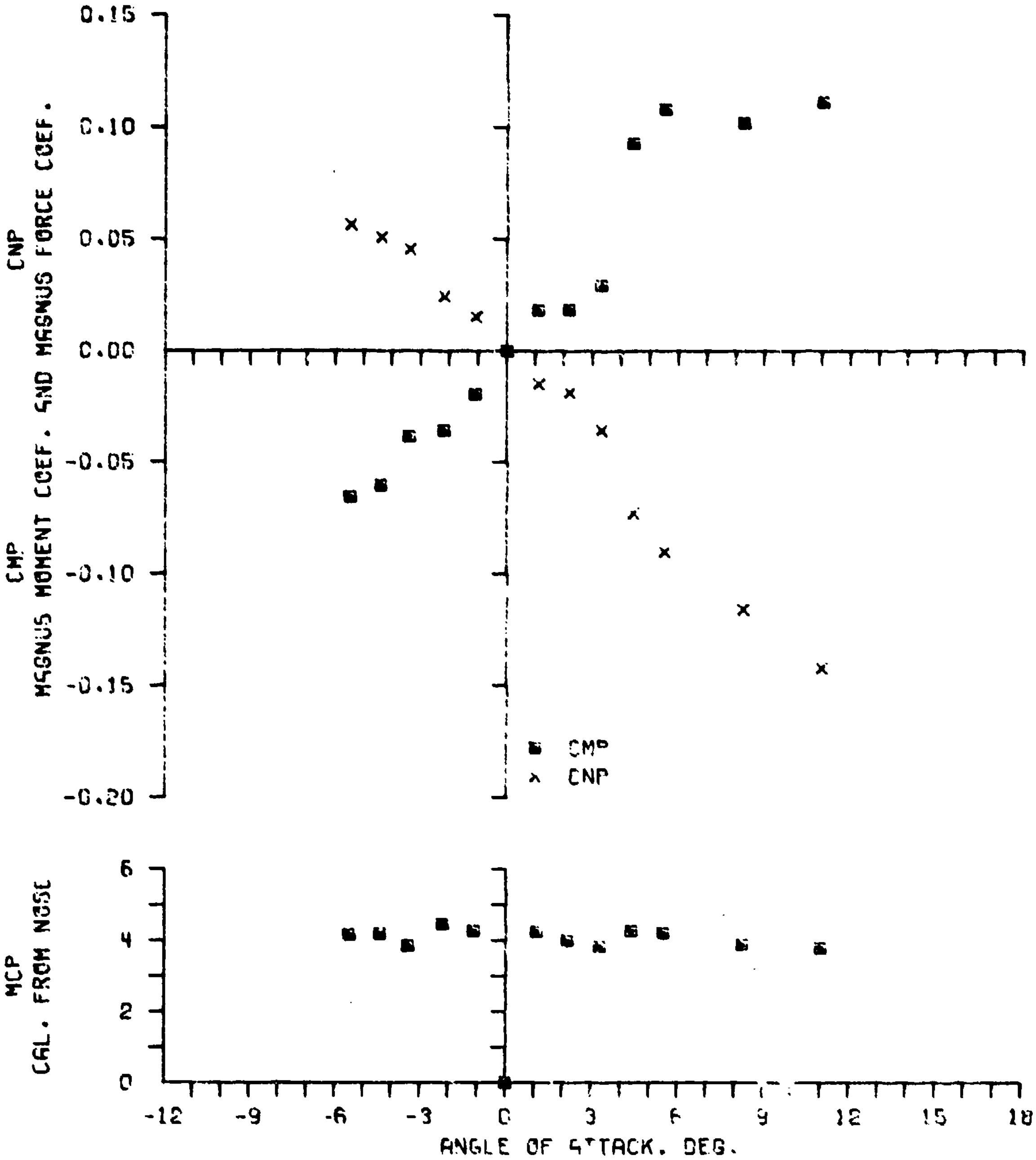


ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG= 5.30 RUN= 16.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED

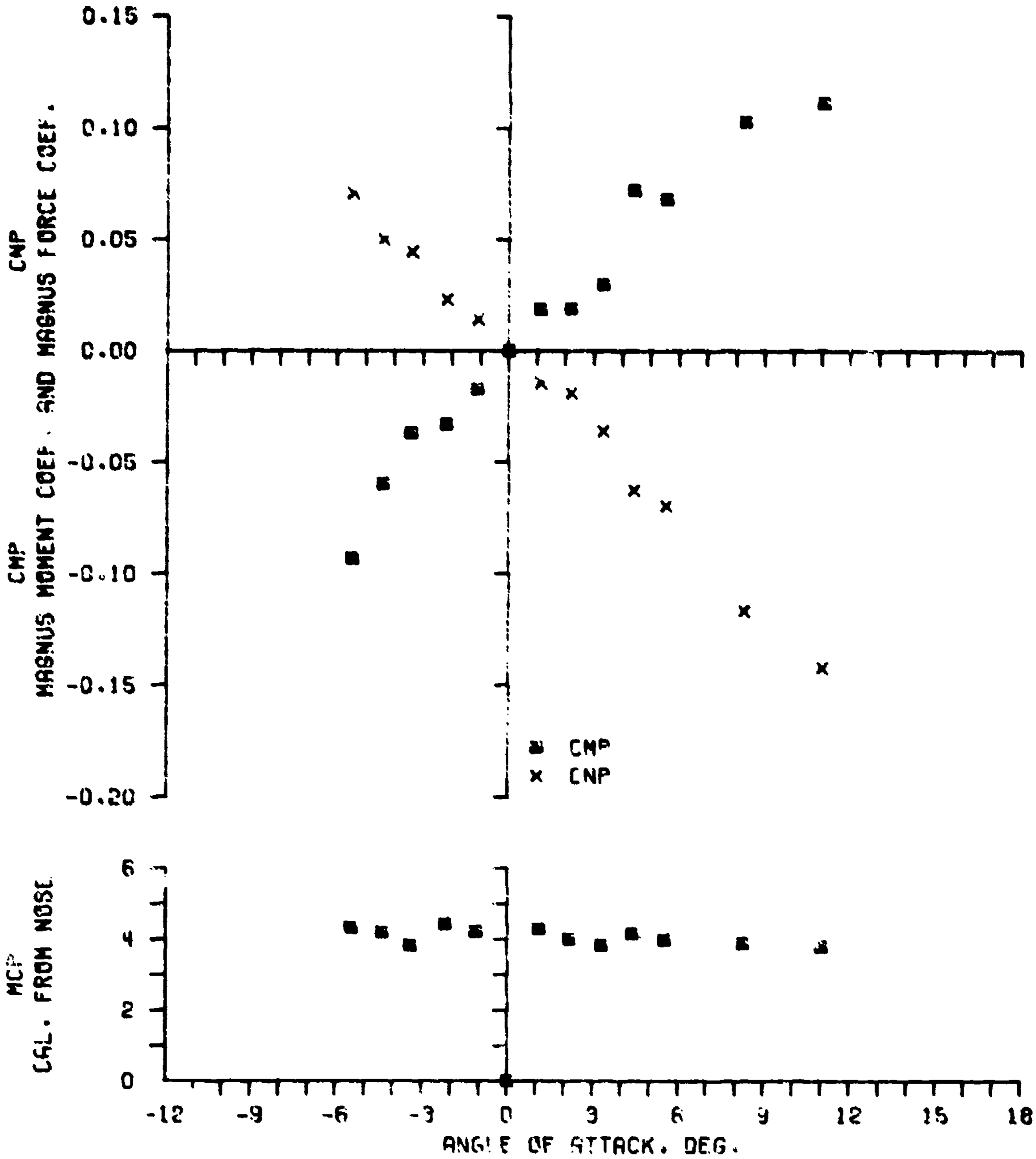
MACH 0.94 PD/V 0.18 R(DIA) 1.42×10^6



ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG= 5.30 RUN= 15.

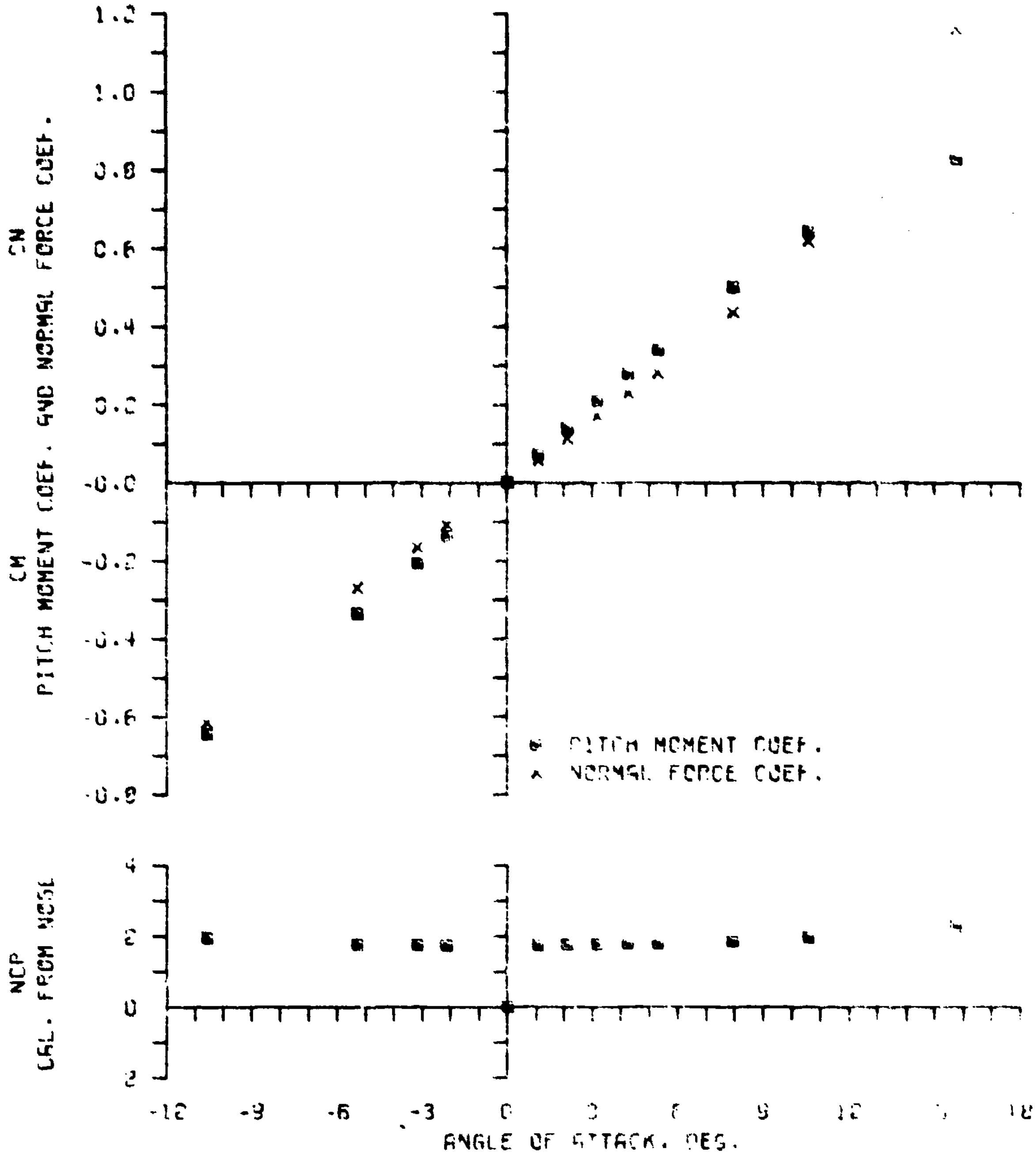
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 0.94 PD/V 0.36 R(DIA) 1.42 X 10^6



ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

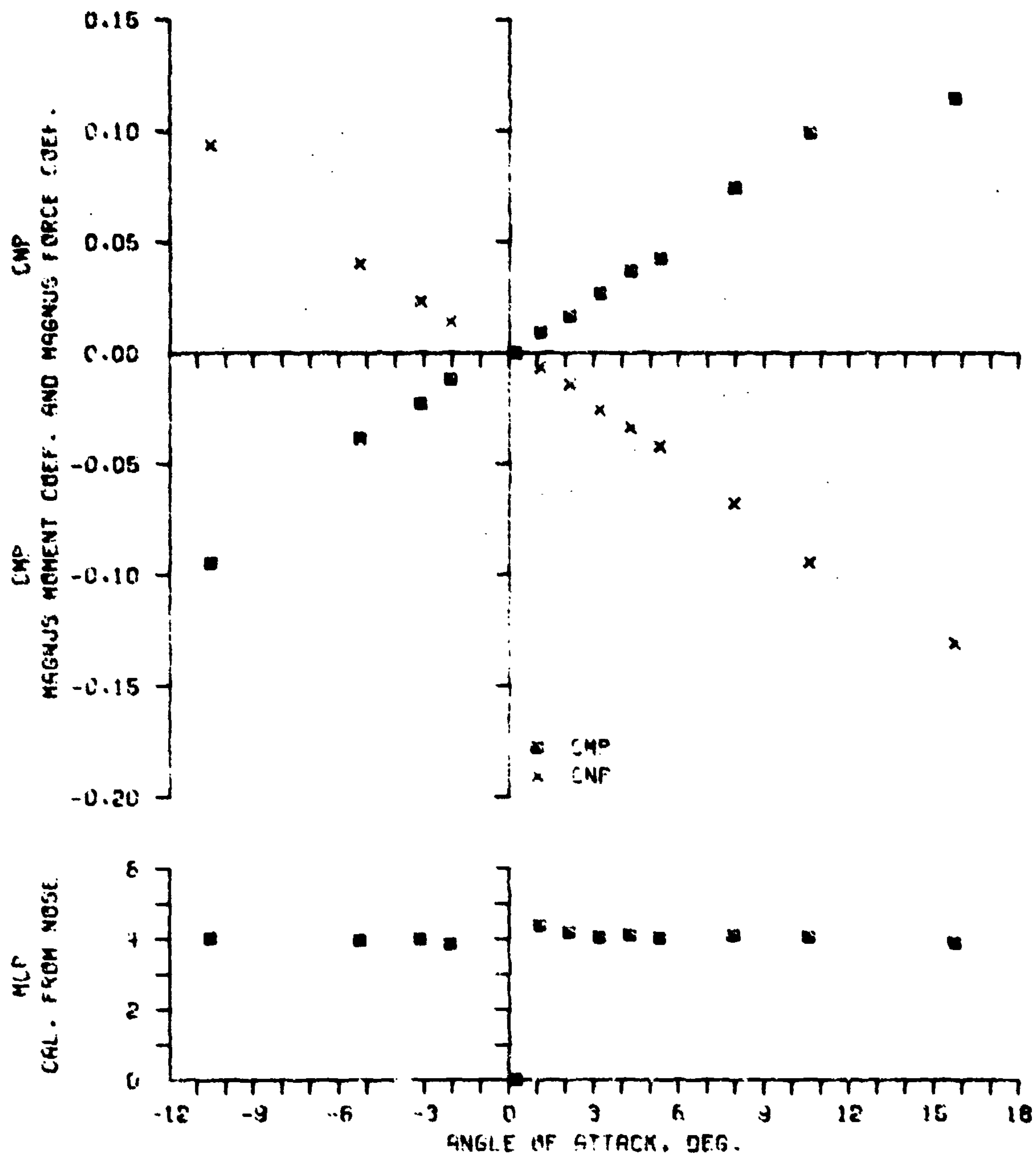
CONFIG= 5.30 RUN= 15.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 1.75 R(DIA) 0.90 X 10^6



CONFIG= 5 30 RUN= 25

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
6 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 1.75 PD/V 0.37 R/DIA) 0.90 X 10^6

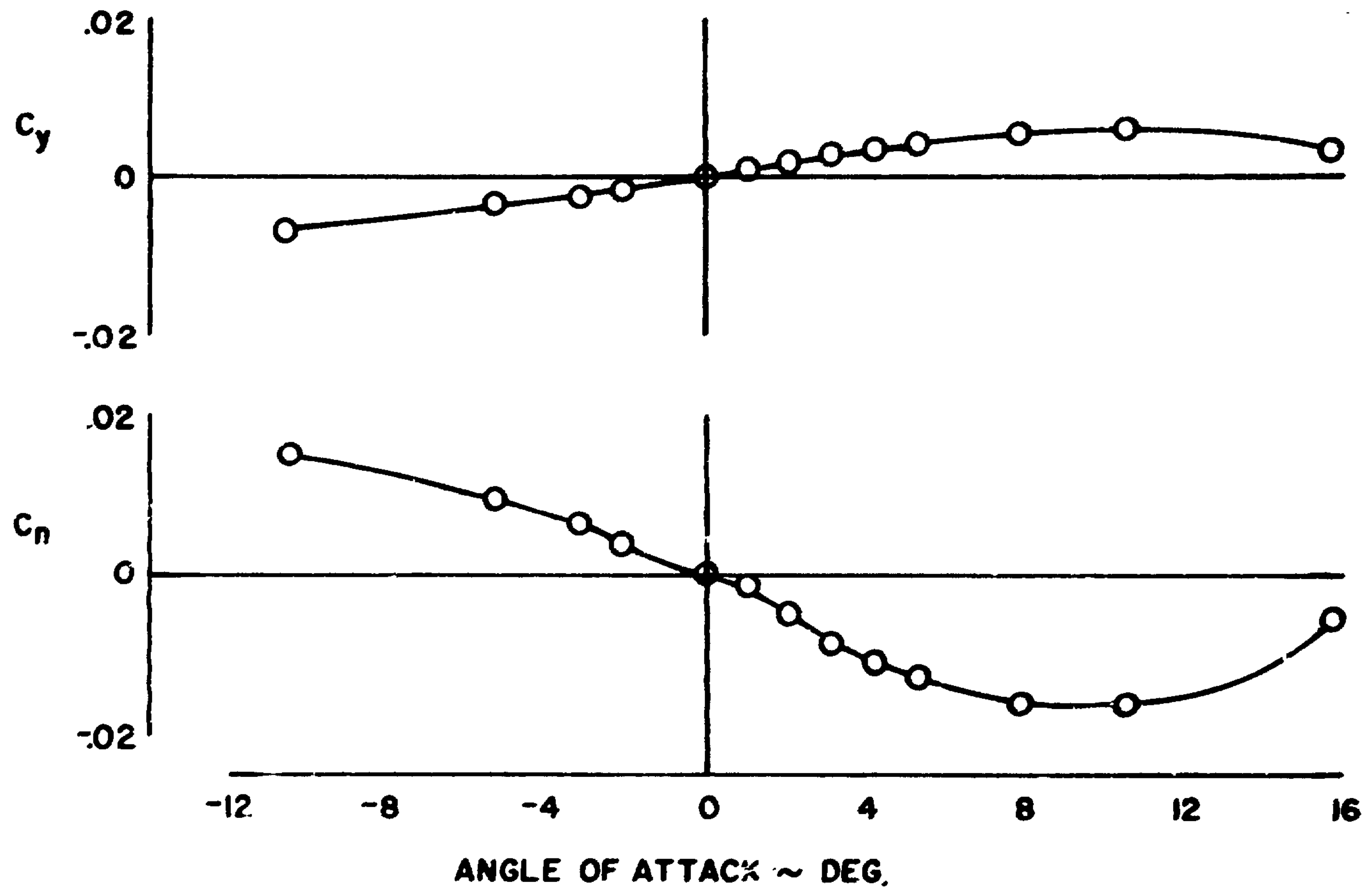


THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND YAWING MOMENT ON NEXT PAGE TO OBTAIN $C_{N_{p_\alpha}}$ AND $C_{m_{p_\alpha}}$.

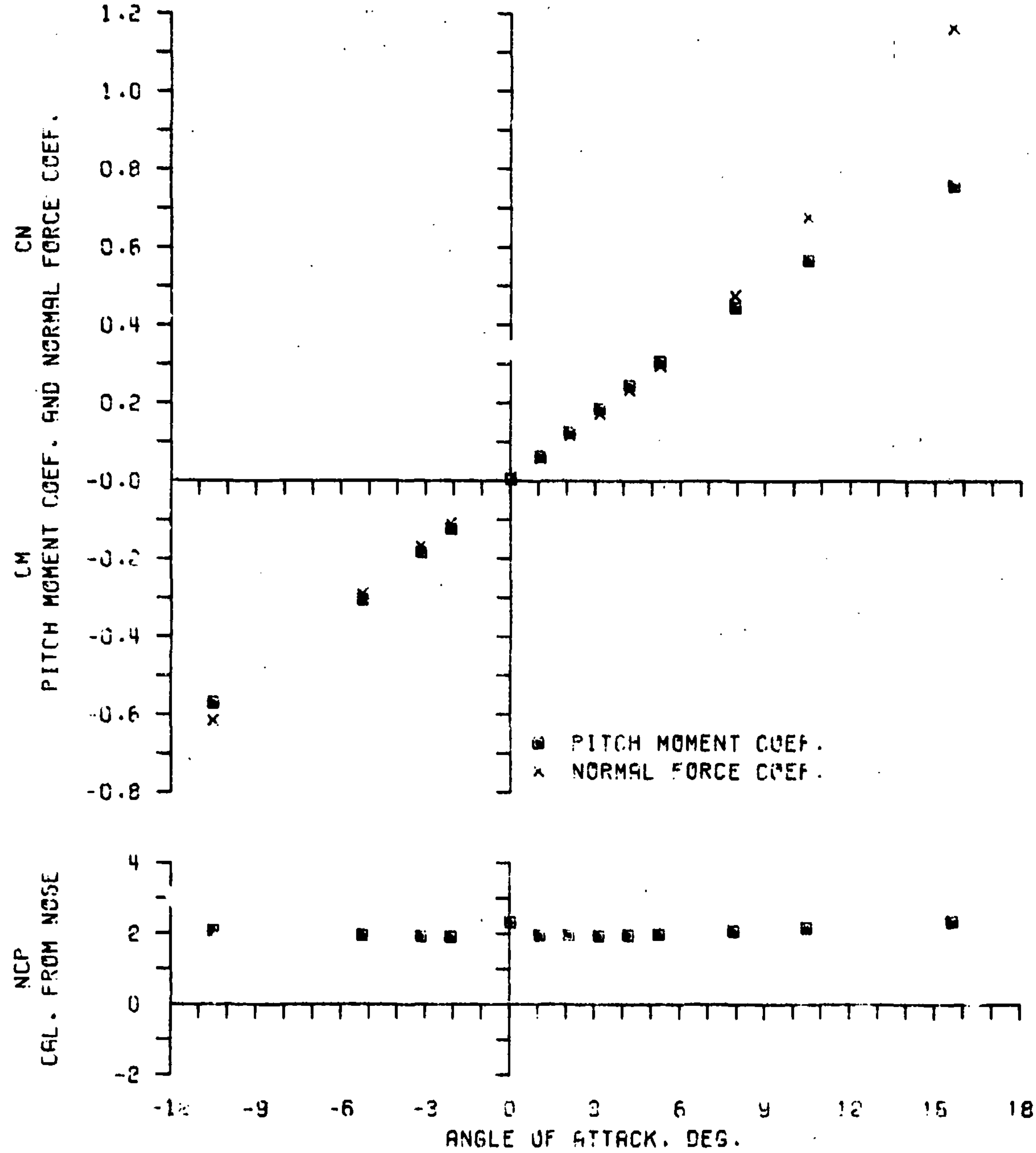
CONFIG= 5.30 RUN= 25.

SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Square Boattail
Mach 1.75 R_d 0.9 X 10^6

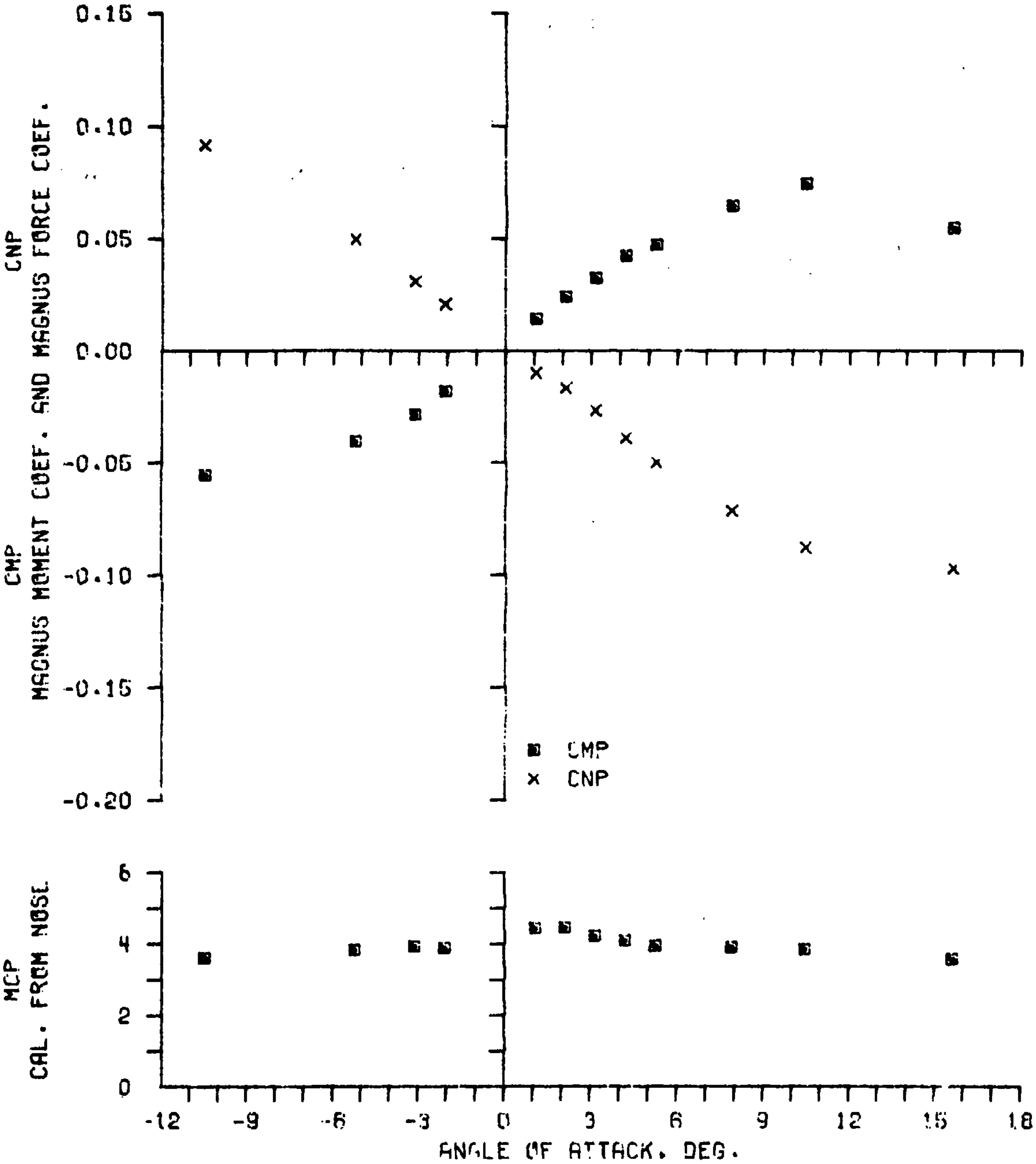


U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 2.50 R(DIA) 0.94 X 10^6



CONFIG= 5.30 RUN= 26.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 2.50 PD/V 0.31 R(DIA) 0.94 X 10^6

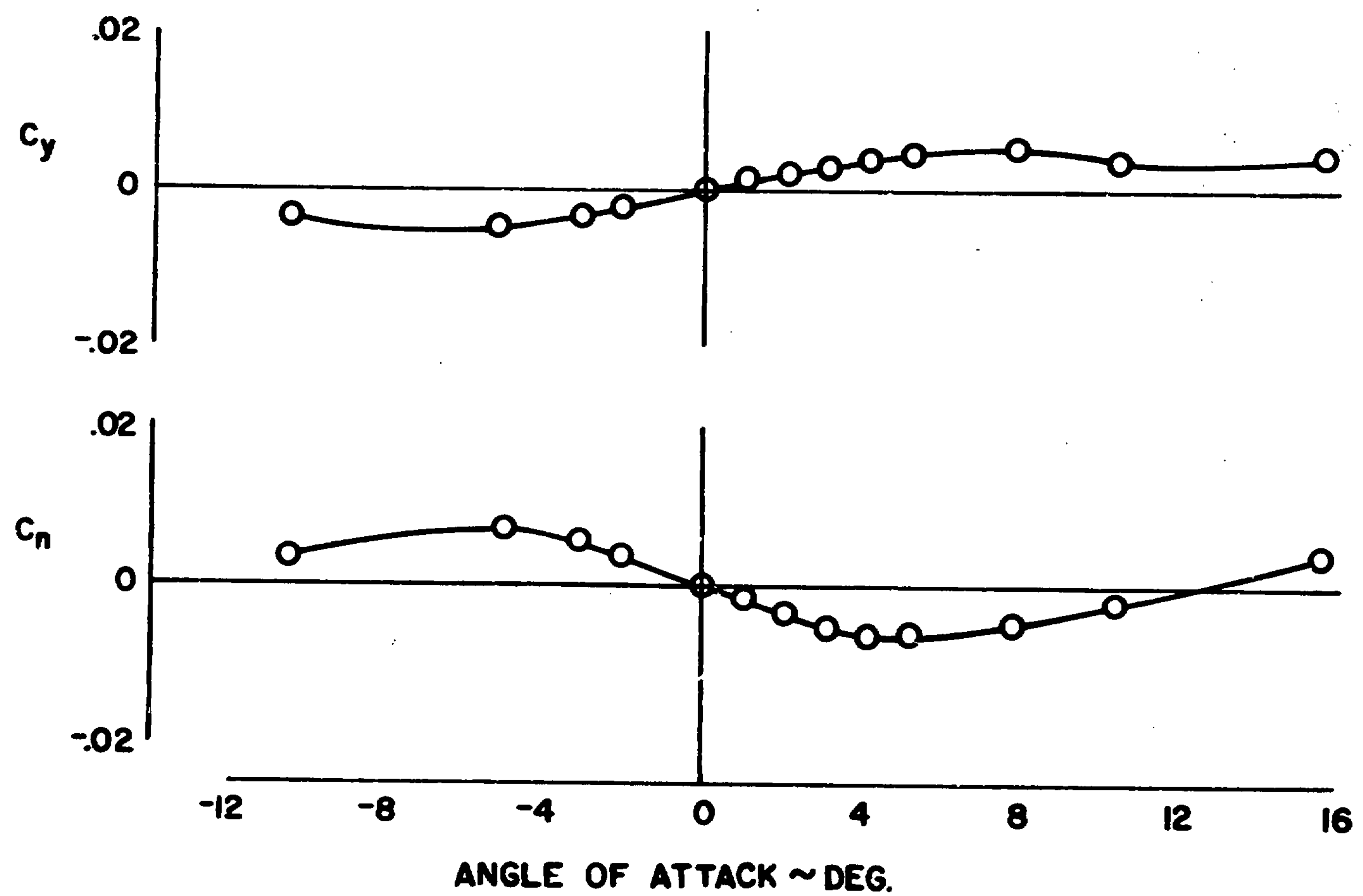


CONFIG= 5.30 RUN= 26.

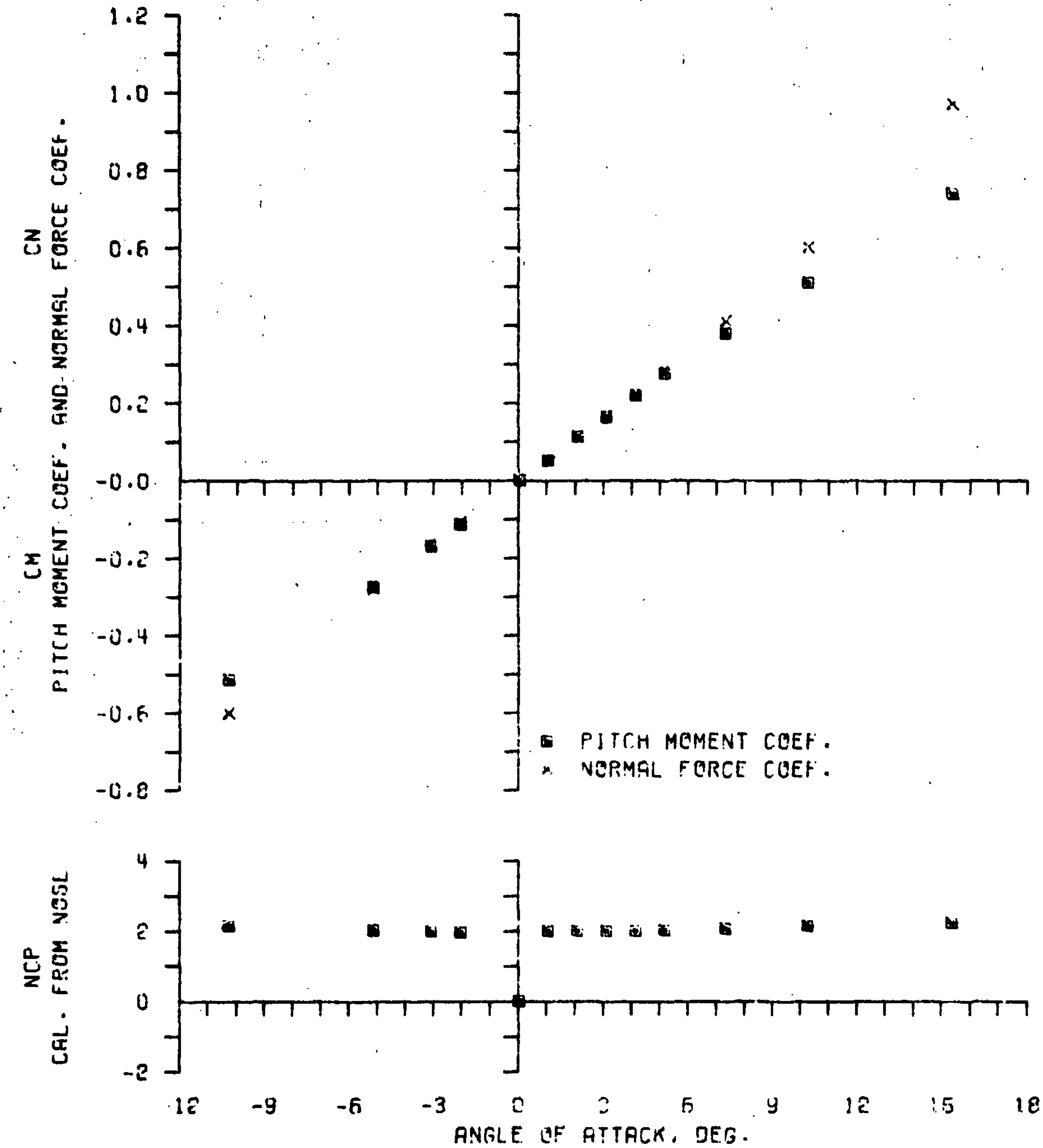
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Square Boattail

Mach 2.5 R_d 0.94 X 10^6

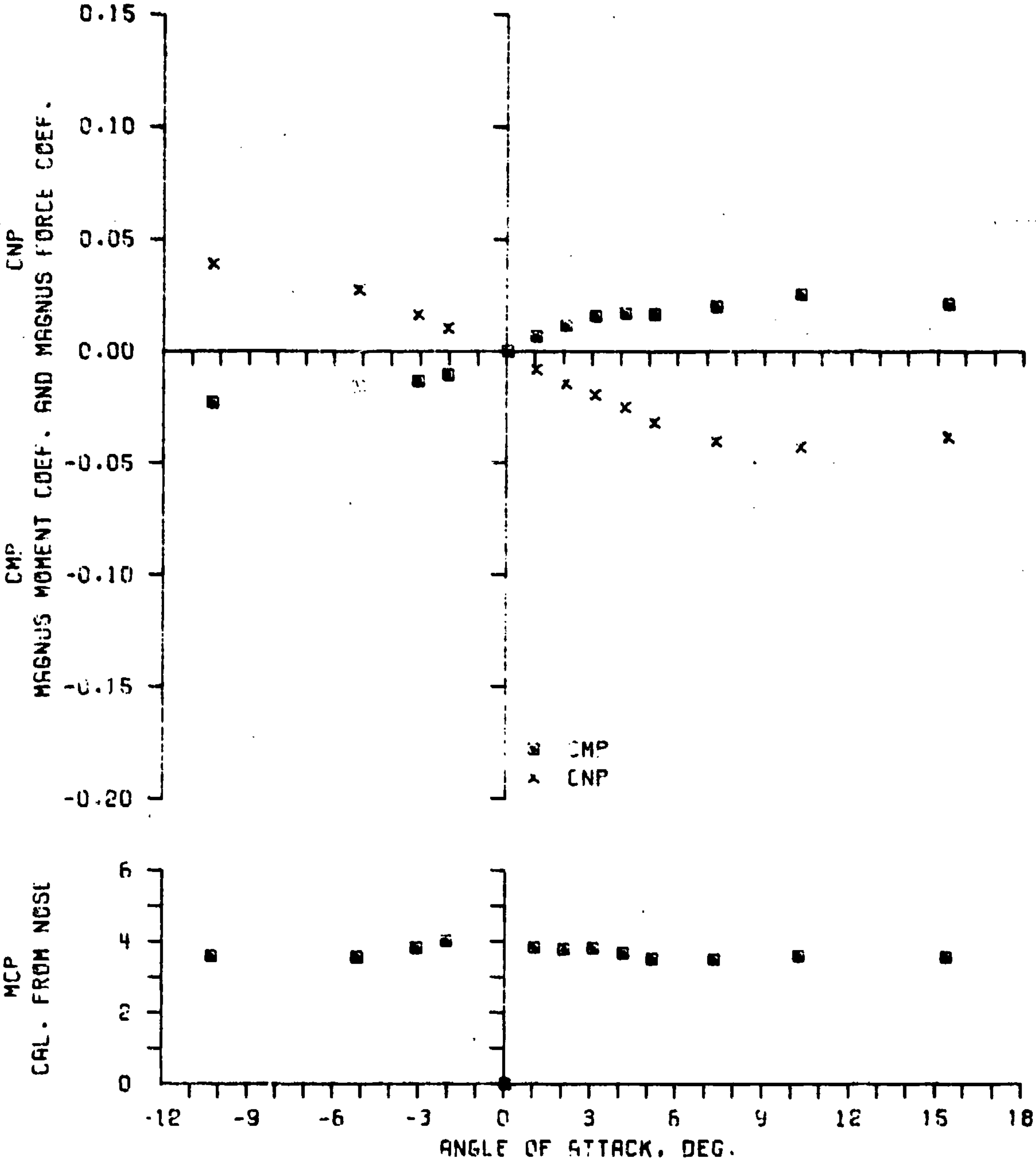


U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL CANTED
MACH 4.00 R(DIA) 0.99 X 10^6



FIG= 5.30 RUN= 27.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL, CANTED
MACH 4.00 PD/V 0.26 R(DIA) 0.99 X 10^6



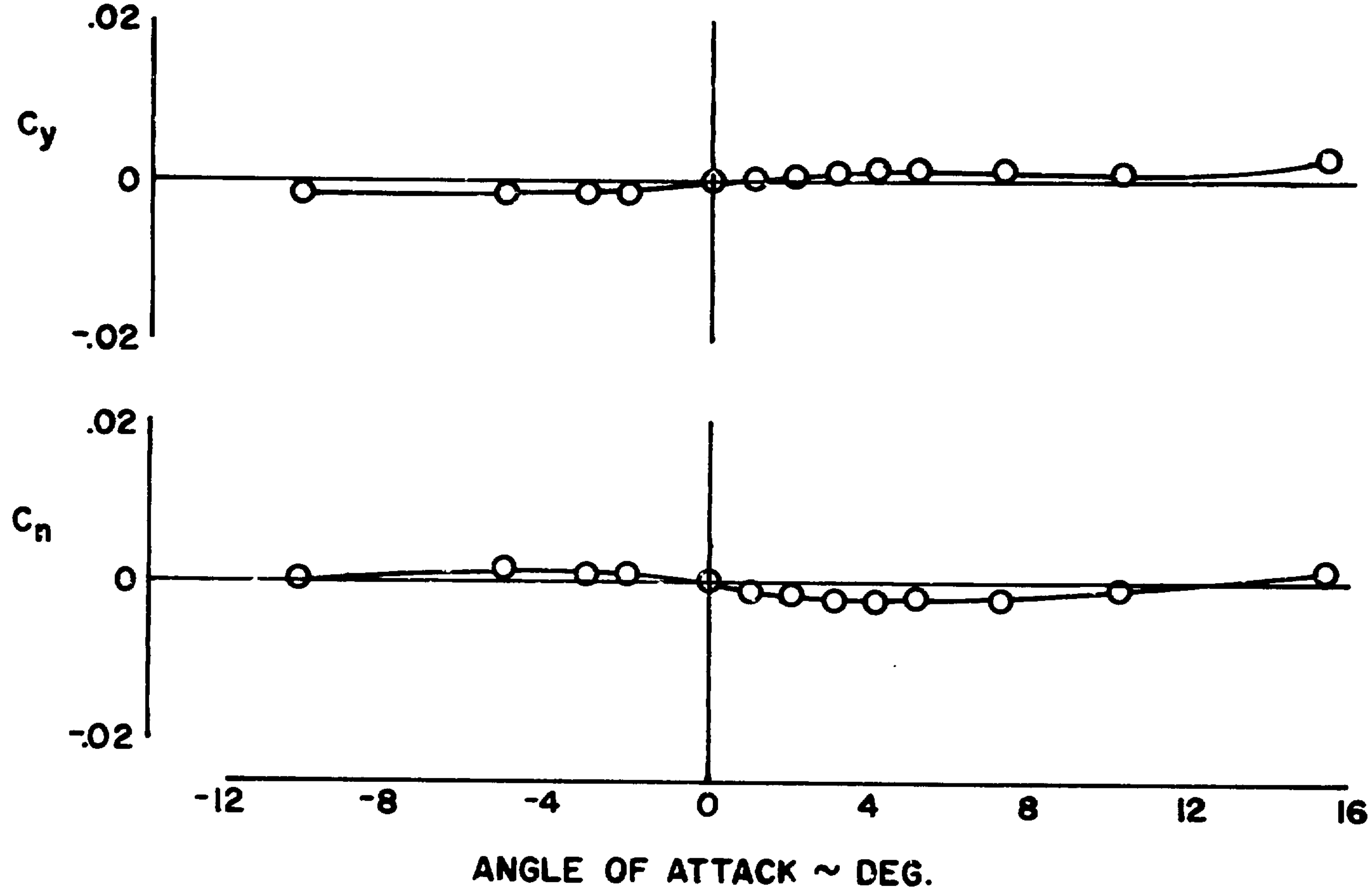
THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND YAWING MOMENT ON NEXT PAGE TO OBTAIN $C_{N_{p_\alpha}}$ AND $C_{m_{p_\alpha}}$.

CONFIG= 5.30 RUN= 27.

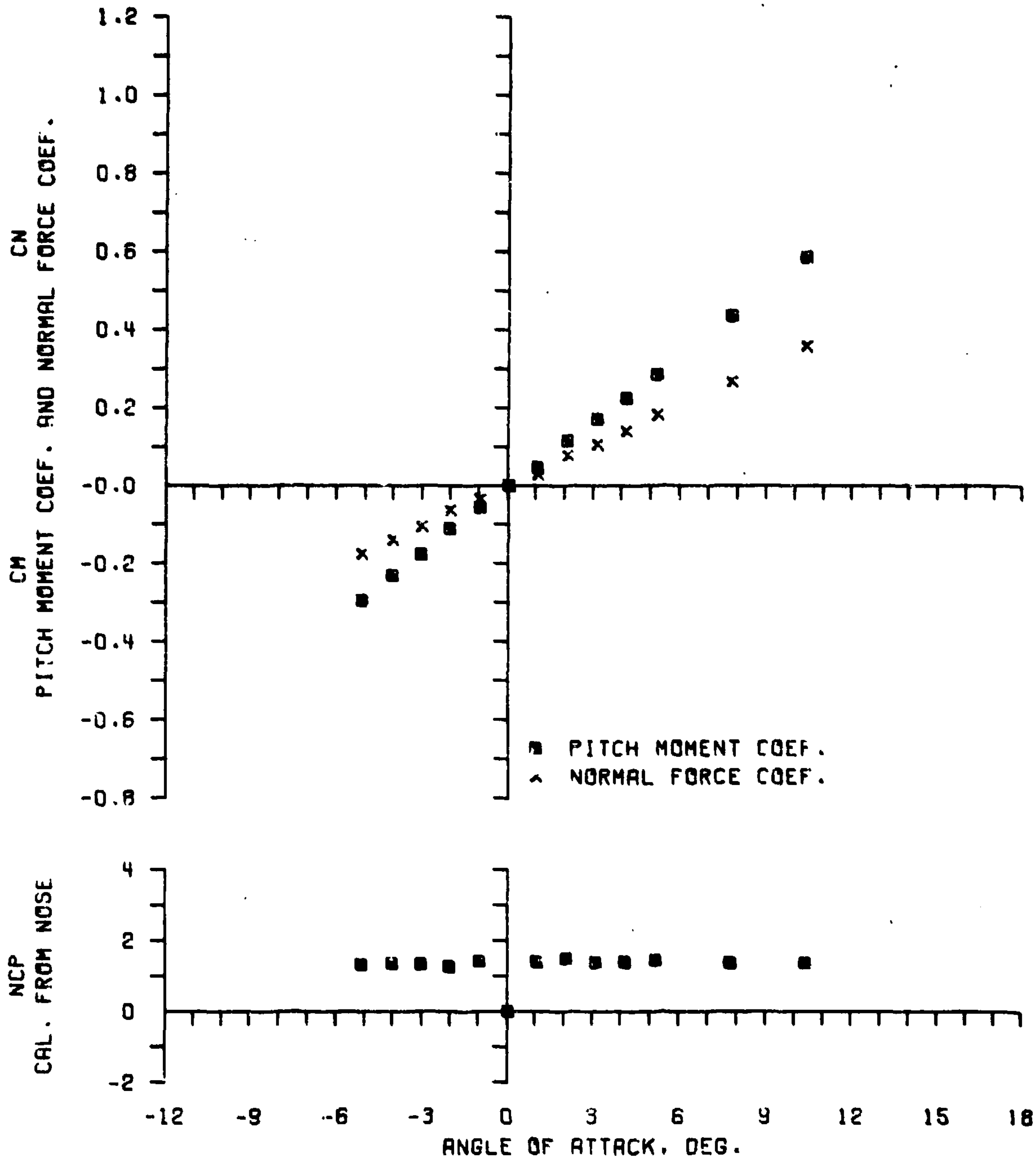
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Square Boattail

Mach 4.0 R_d 0.99 X 10^6

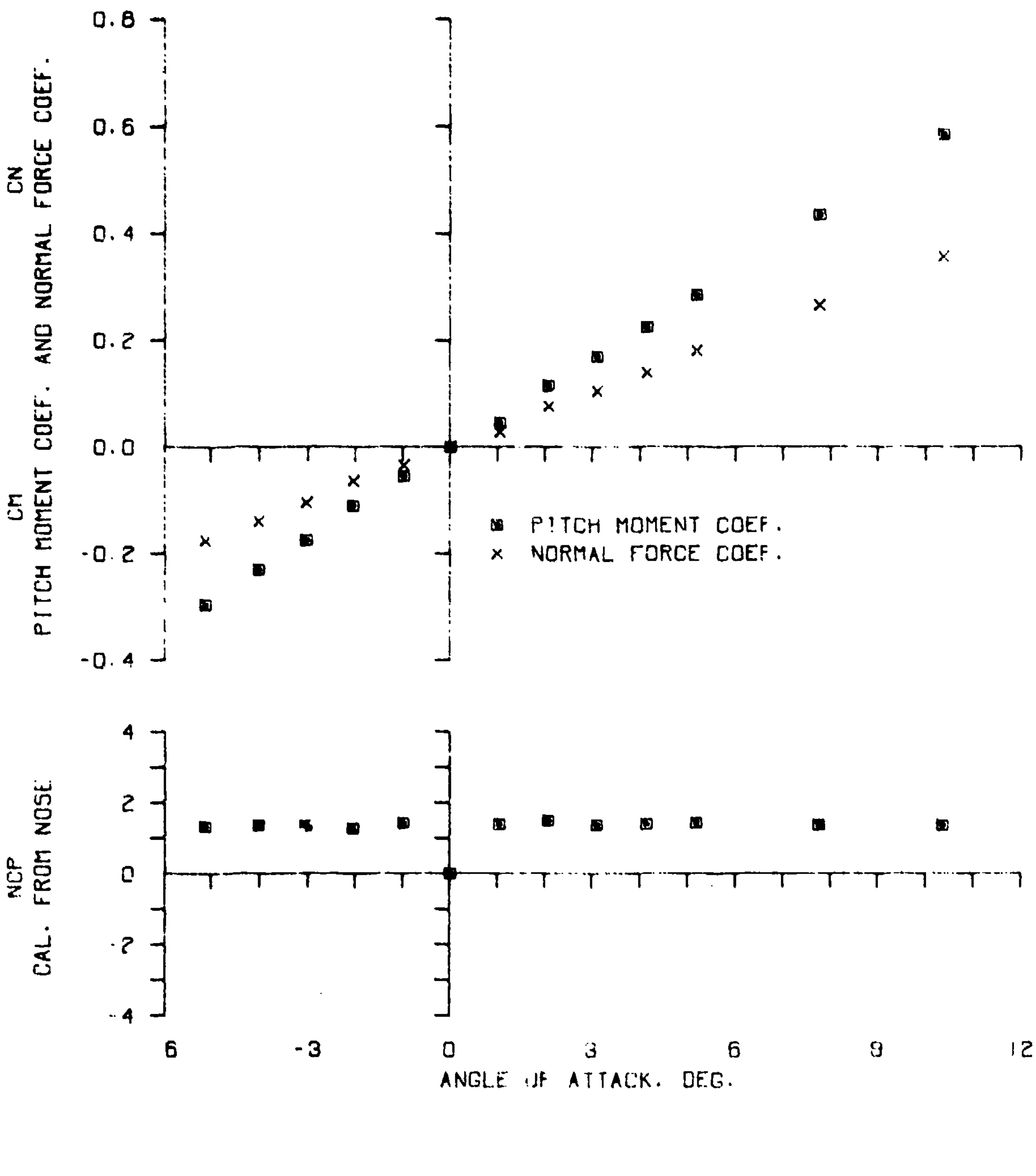


U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAIL W/FINS, STRAIGHT
MACH 0.50 ROLL ZERO DEG. R(DIA) 1.00 X 10^6



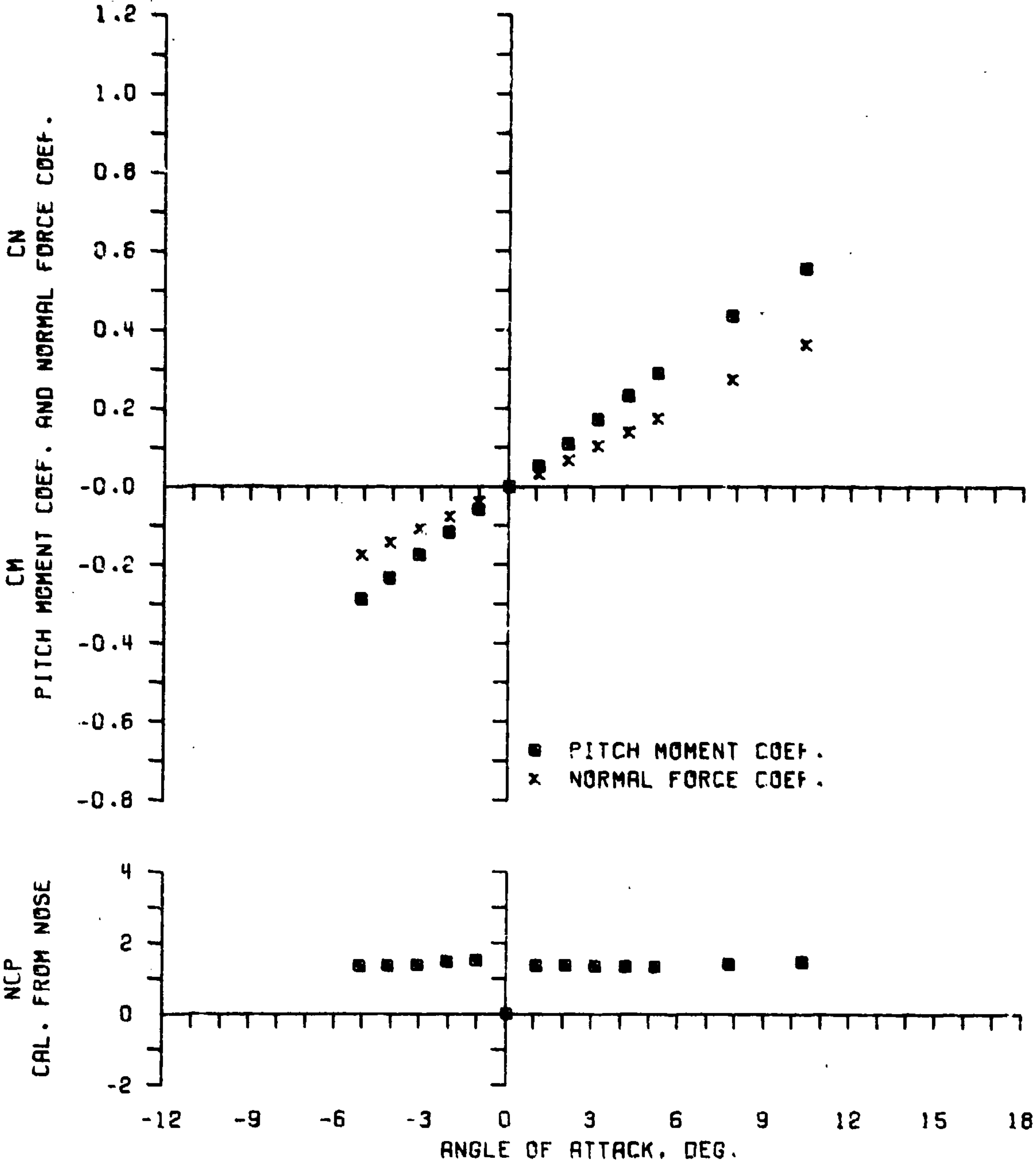
CONFIG= 5.40 RUN= 43.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNEL BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOAT-TAIL-W-FINS-STRAIGHT
MACH 0.50 RE PER FT. 2.834 X 10^6



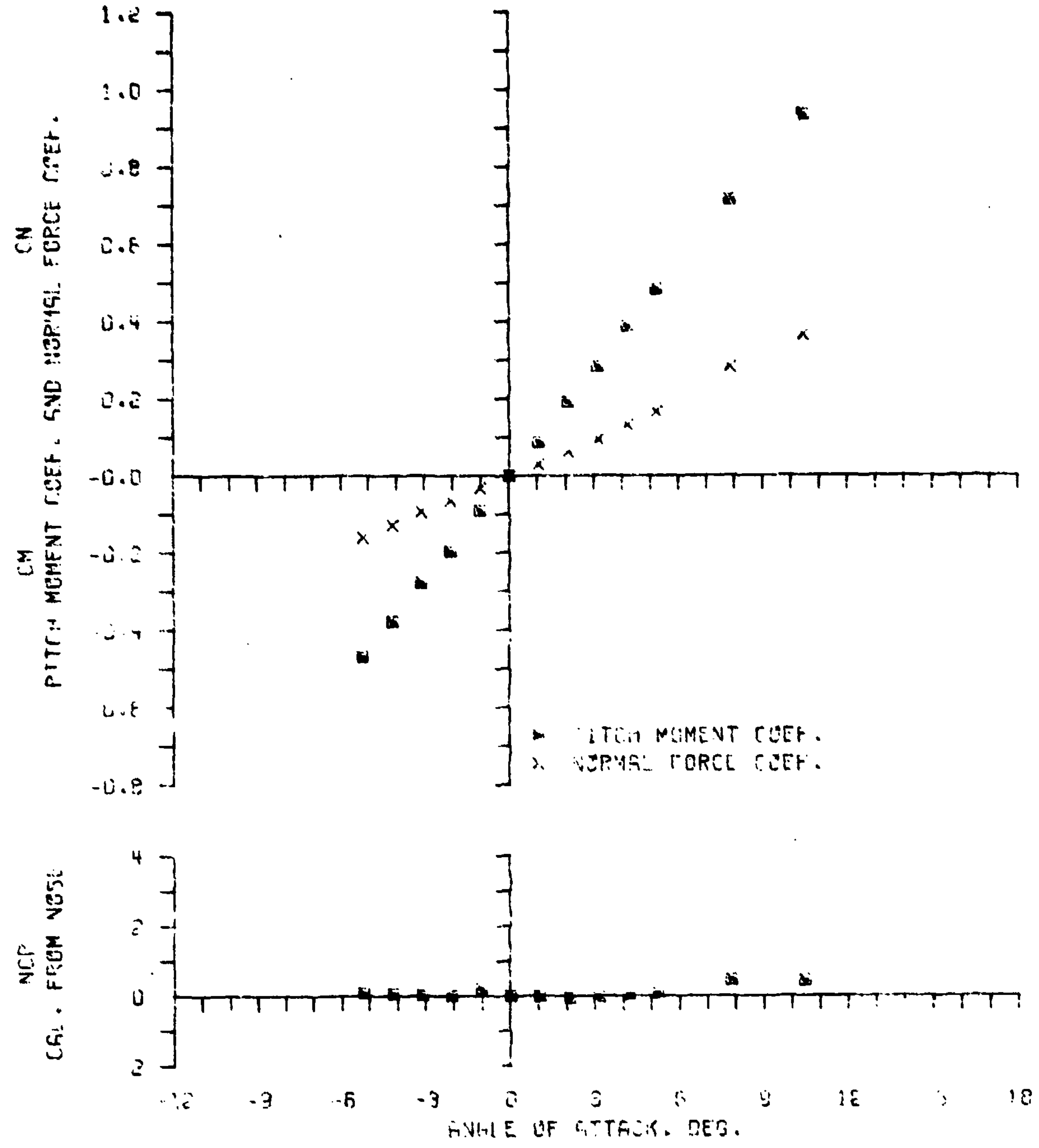
CONFIG= 5.40 RUN= 43.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS. STRAIGHT
MACH 0.50 ROLL 45 DEG. R(DIA) 1.00 X 10 6



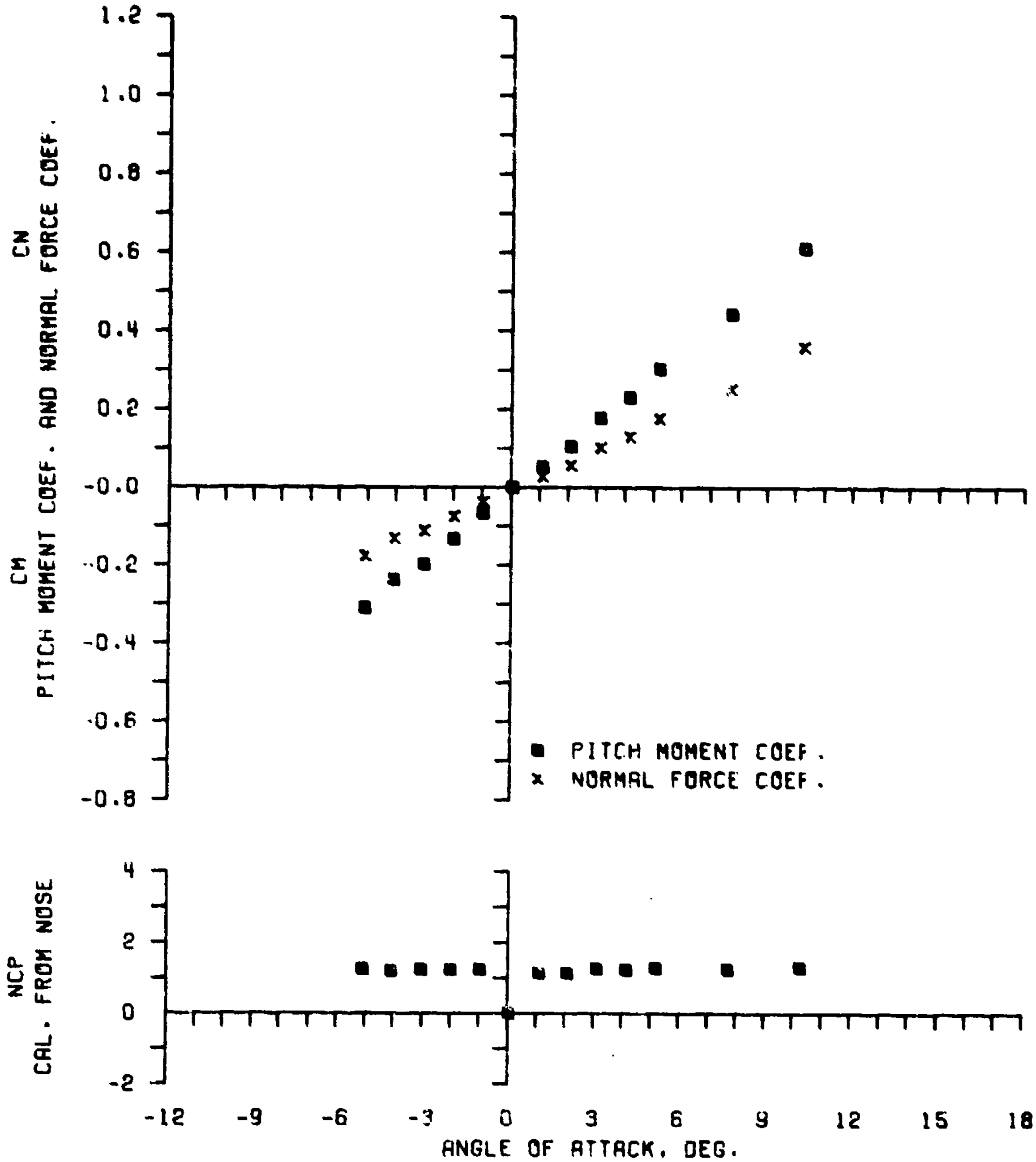
CONFIG= 5.40 RUN= 46.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS- STRAIGHT
MACH 0.50 RE/DIA 1.05 X 10^6



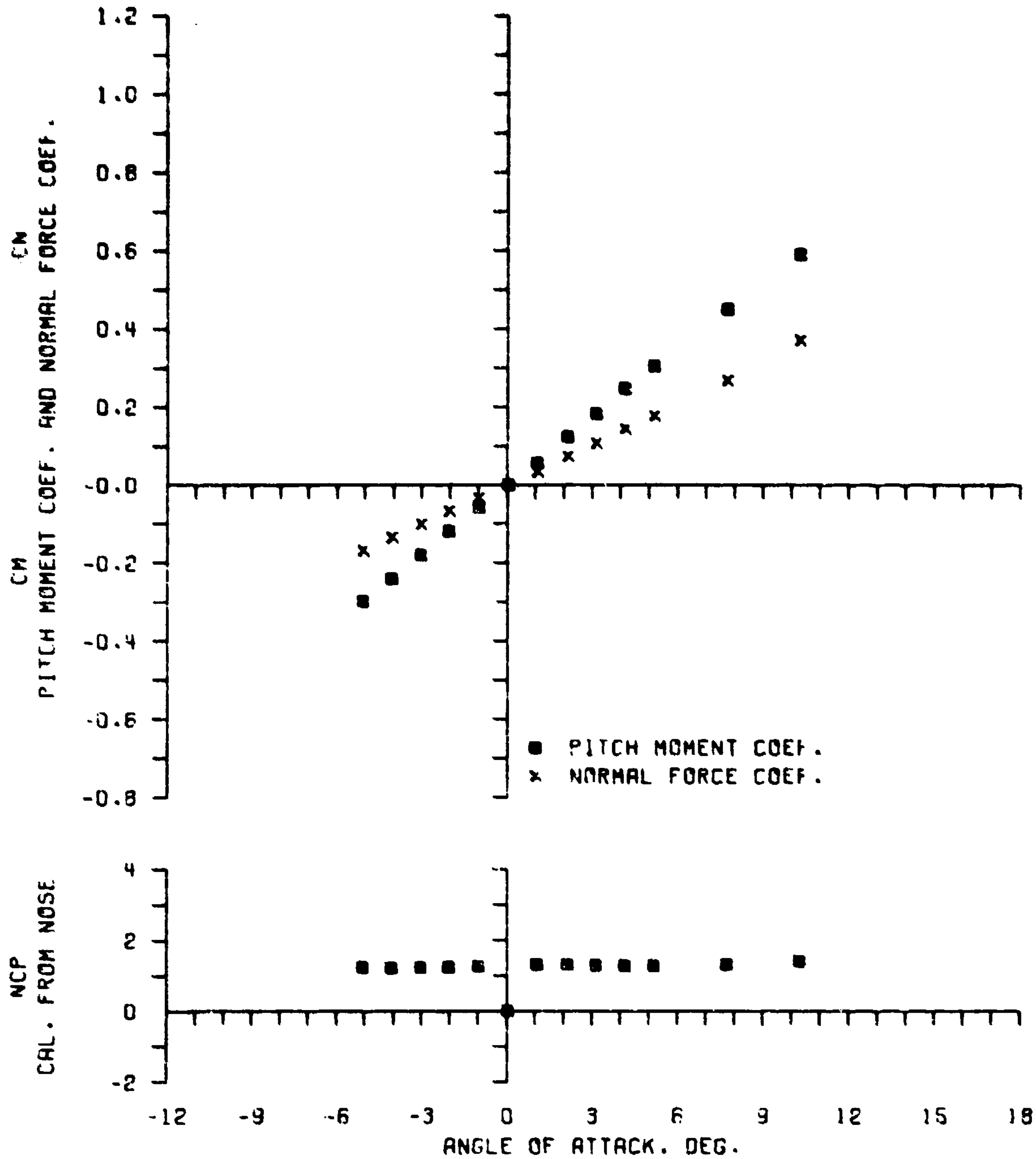
CONFIG= 5 40 RUN= 30.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, STRAIGHT
MACH 0.70 ROLL ZERO DEG. R(DIA) 0.57 X 10^6



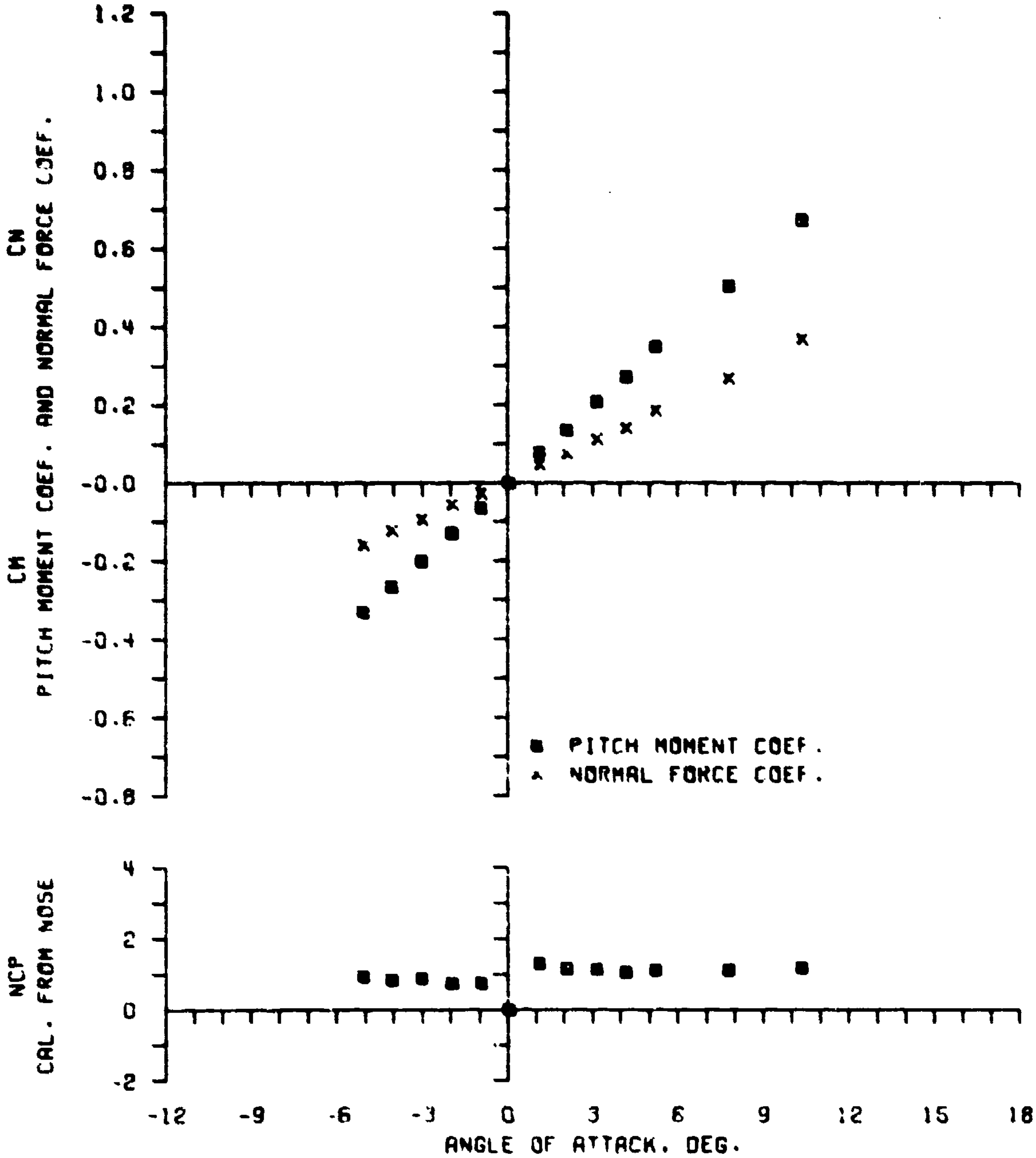
CONFIG= 5.40 RUN= 42.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, STRAIGHT
MACH 0.70 ROLL 45 DEG. R(DIA) 0.57 X 10 ^{6}



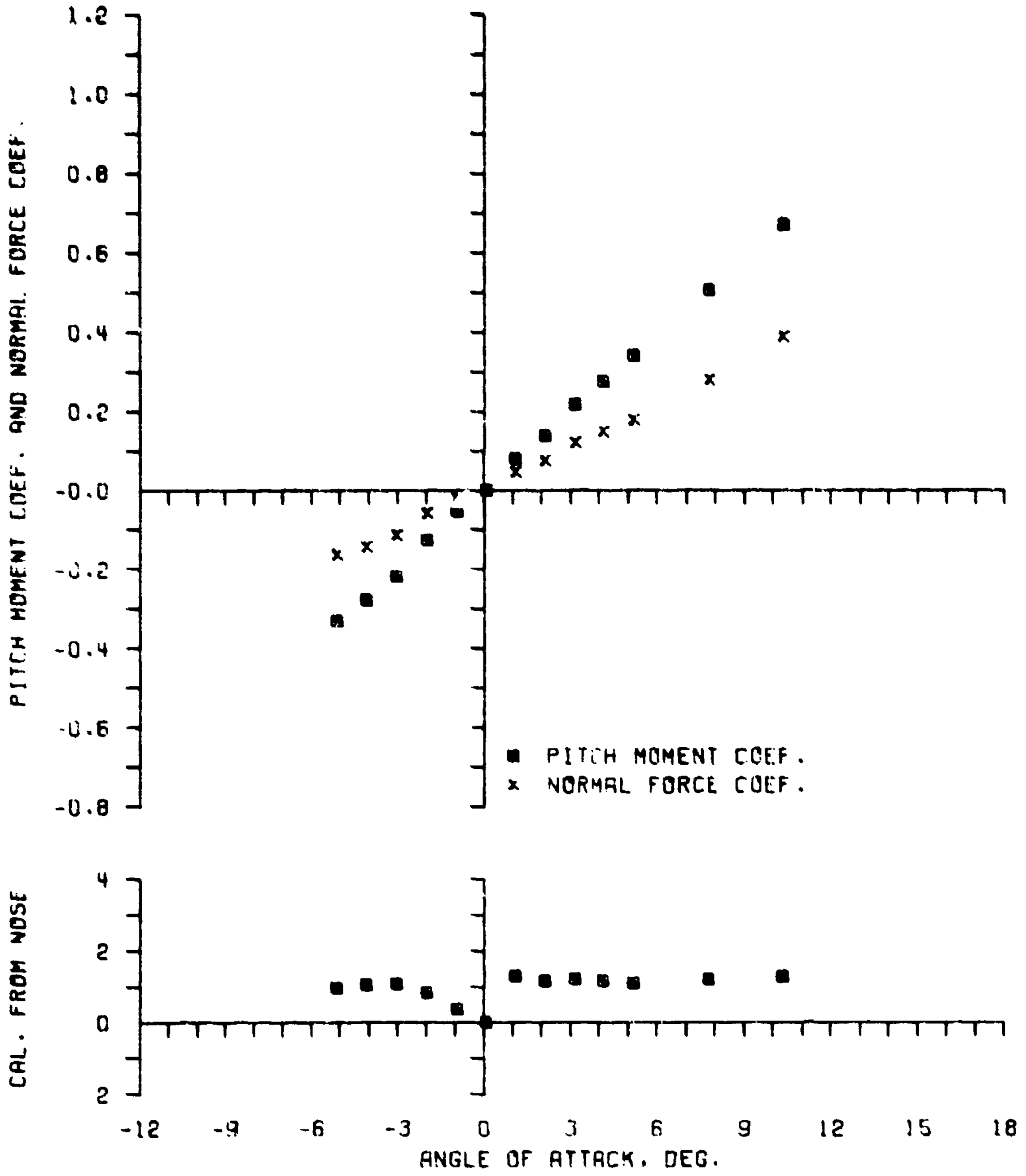
CONFIG= 5.40 RUN= 45.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, STRAIGHT
MACH 0.90 ROLL ZERO DEG. R(DIA) 0.49 X 10^6



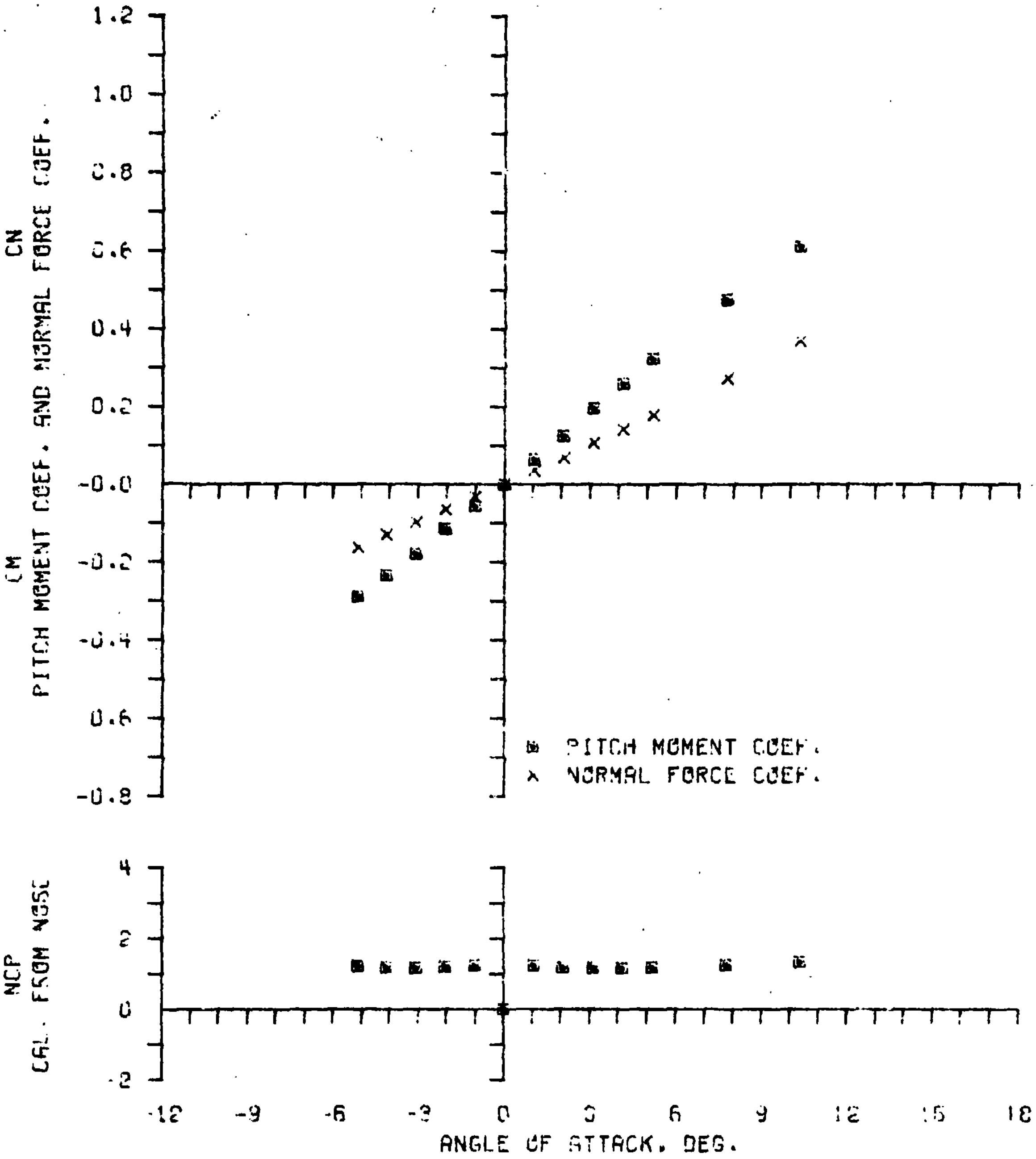
CONFIG= 5.40 RUN= 41.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
AMES 12 FT. SUBSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAIL W/FINS. STRAIGHT
MACH 0.89 ROLL 45 DEG. R(DIA) 0.48 X 10 [6]



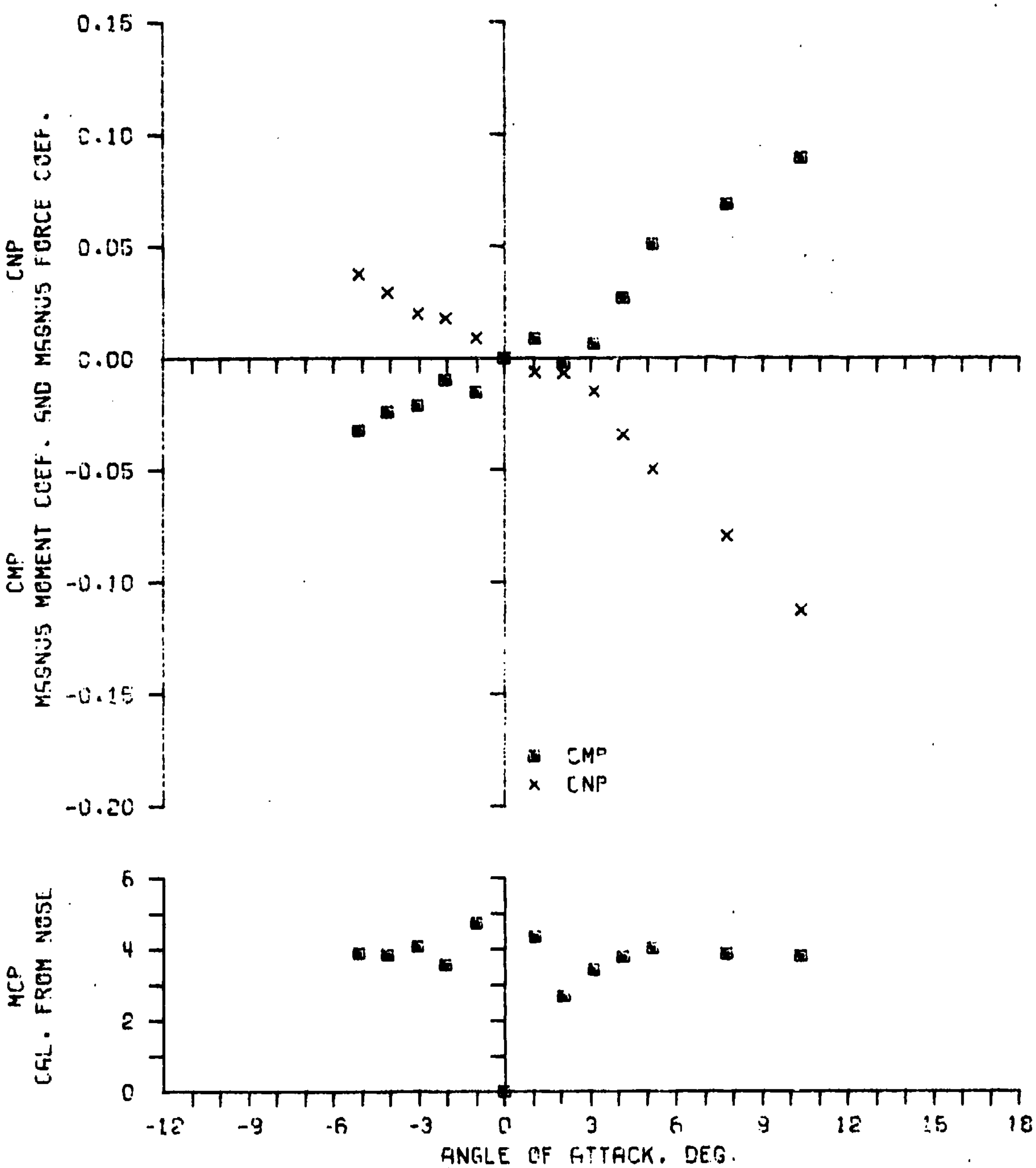
CONFIG= 5.40 RUN= 44.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, CANTED
MACH 0.50 R(DIA) 1.05 X 10^6



CONFIG= 5.50 RUN= 21.

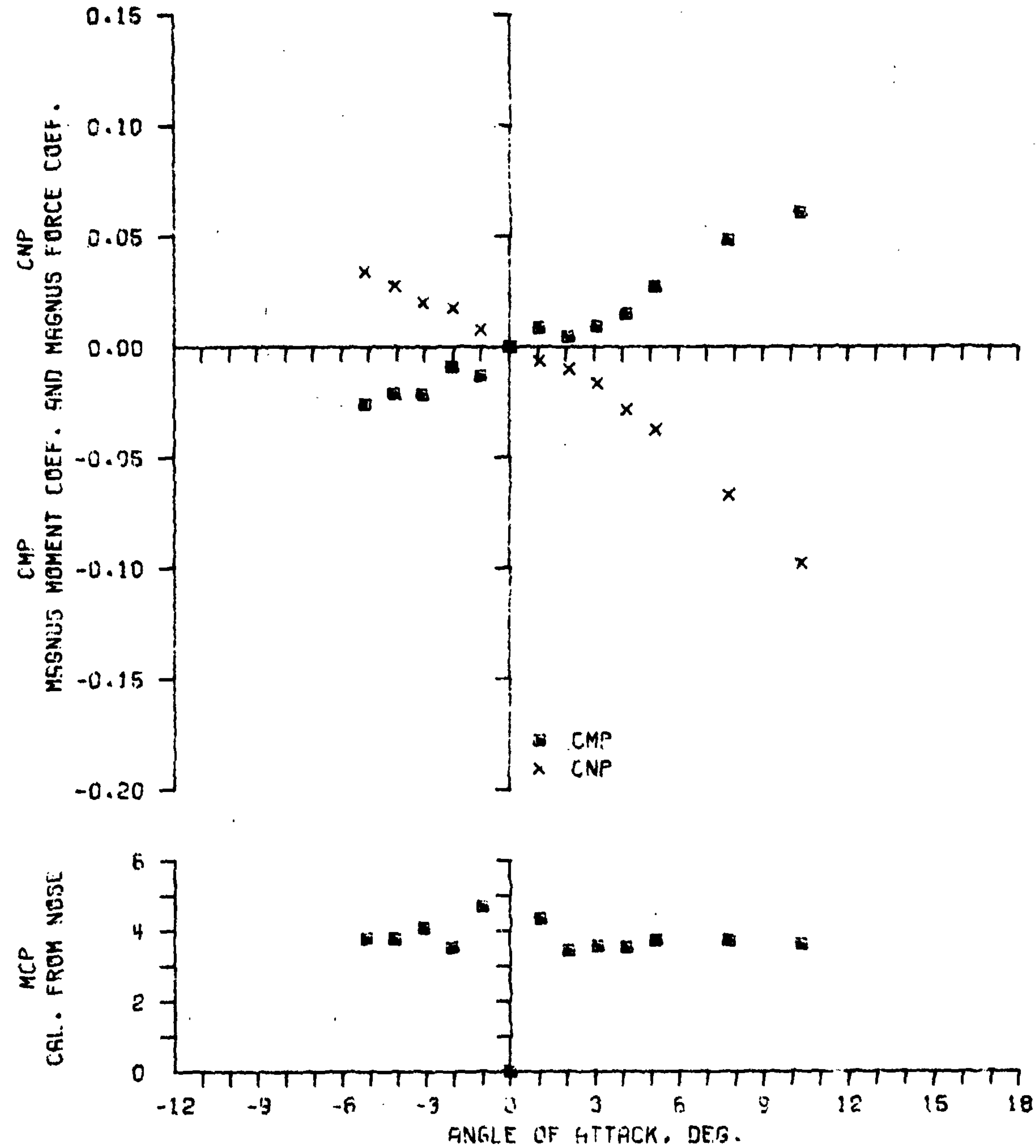
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, CANTED
MACH 0.50 PD/V 0.33 R(DIA) 1.06 X 10^6



ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG= 5.50 RUN= 20.

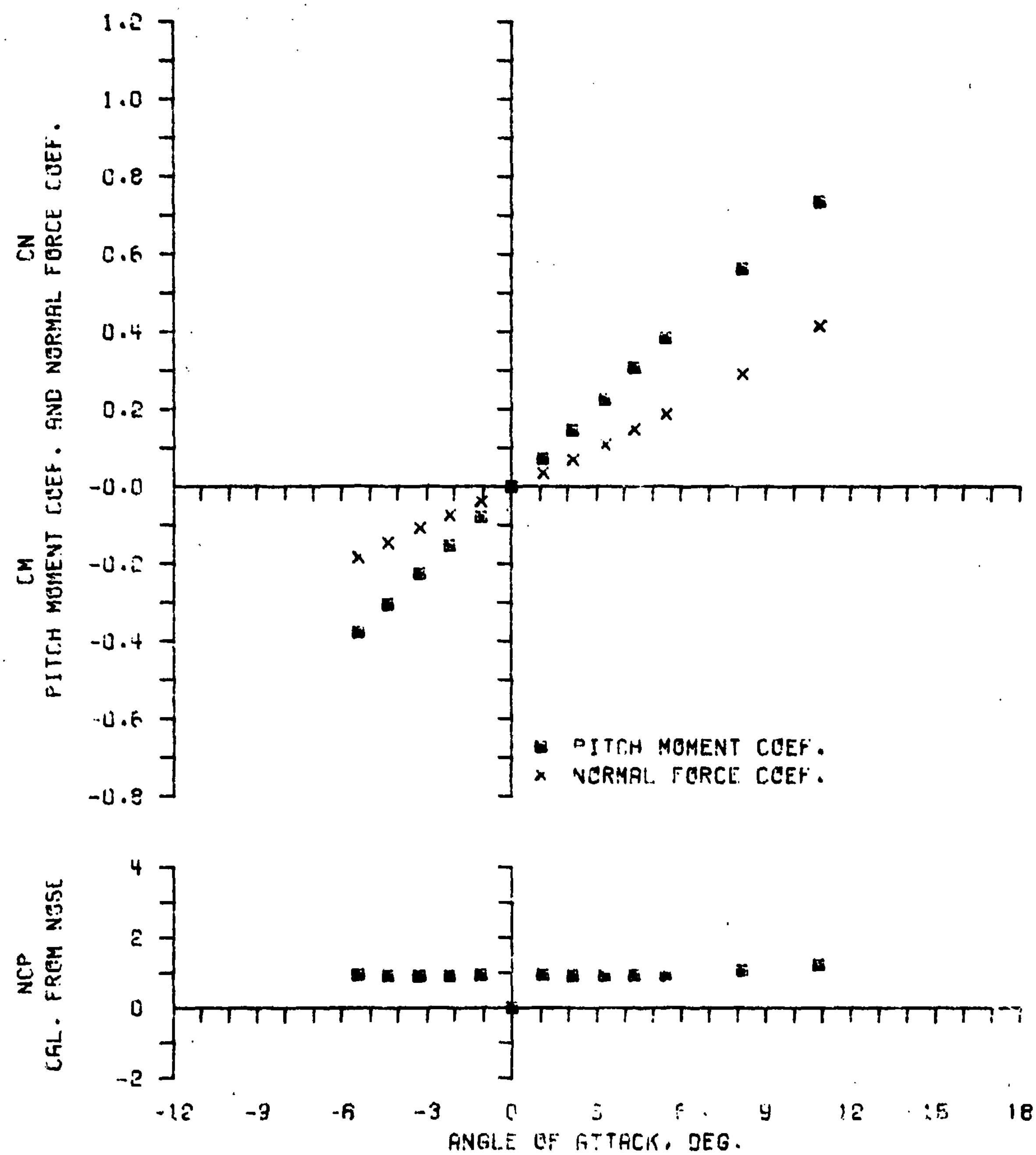
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, CANTED
MACH 0.50 PD/V 0.66 R(DIA) 1.06 X 10[6]



ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

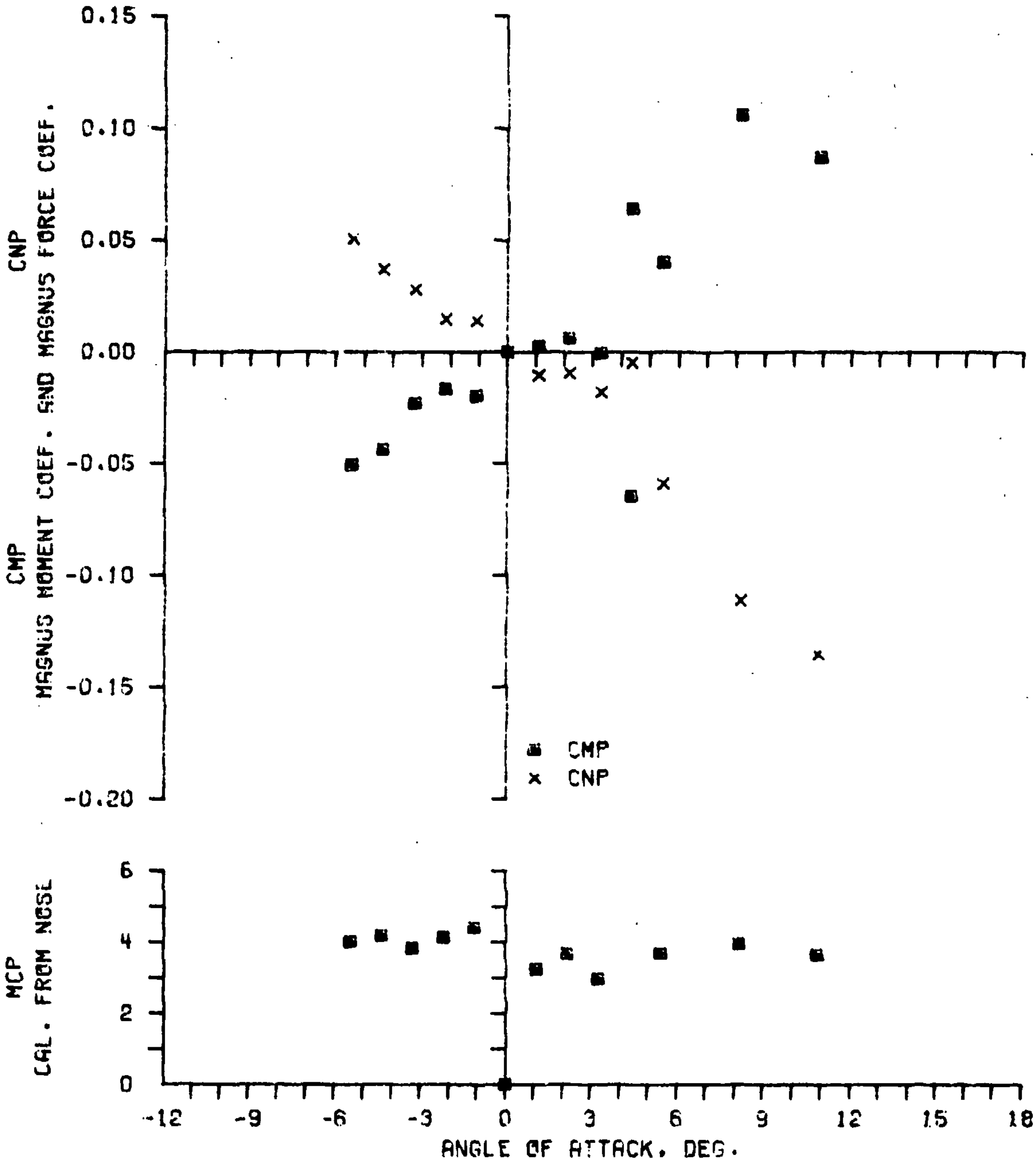
CONFIG= 6.50 RUN= 20.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, CANTED
MACH 0.90 R(DIA) 1.39 X 10^6



CONFIG= 6 RUN= 23

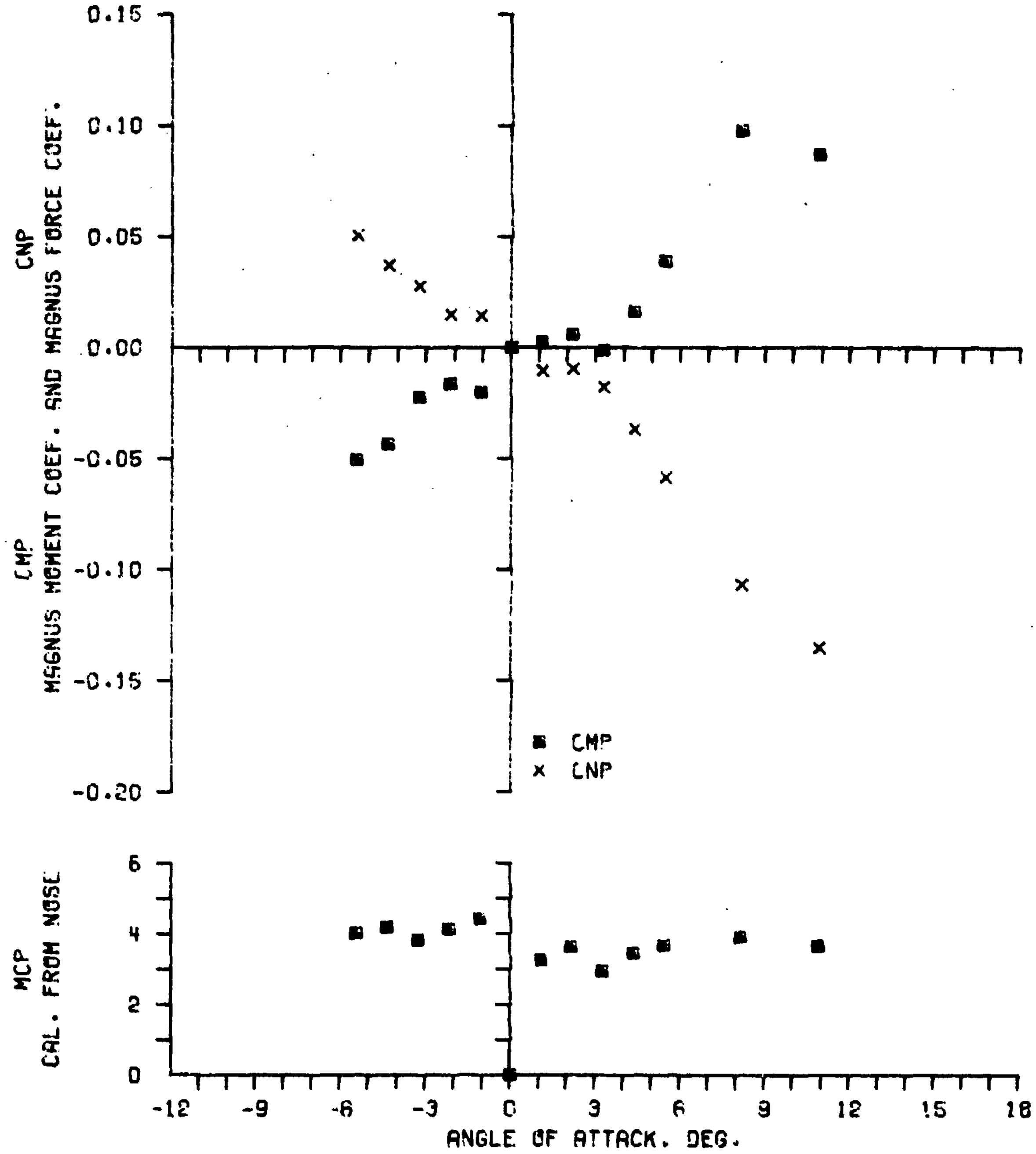
U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH. EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET. SQUARE BOATTAIL W/FINS. CANTED
MACH 0.90 PD/V 0.19 R(DIA) 1.40 X 10^6



ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

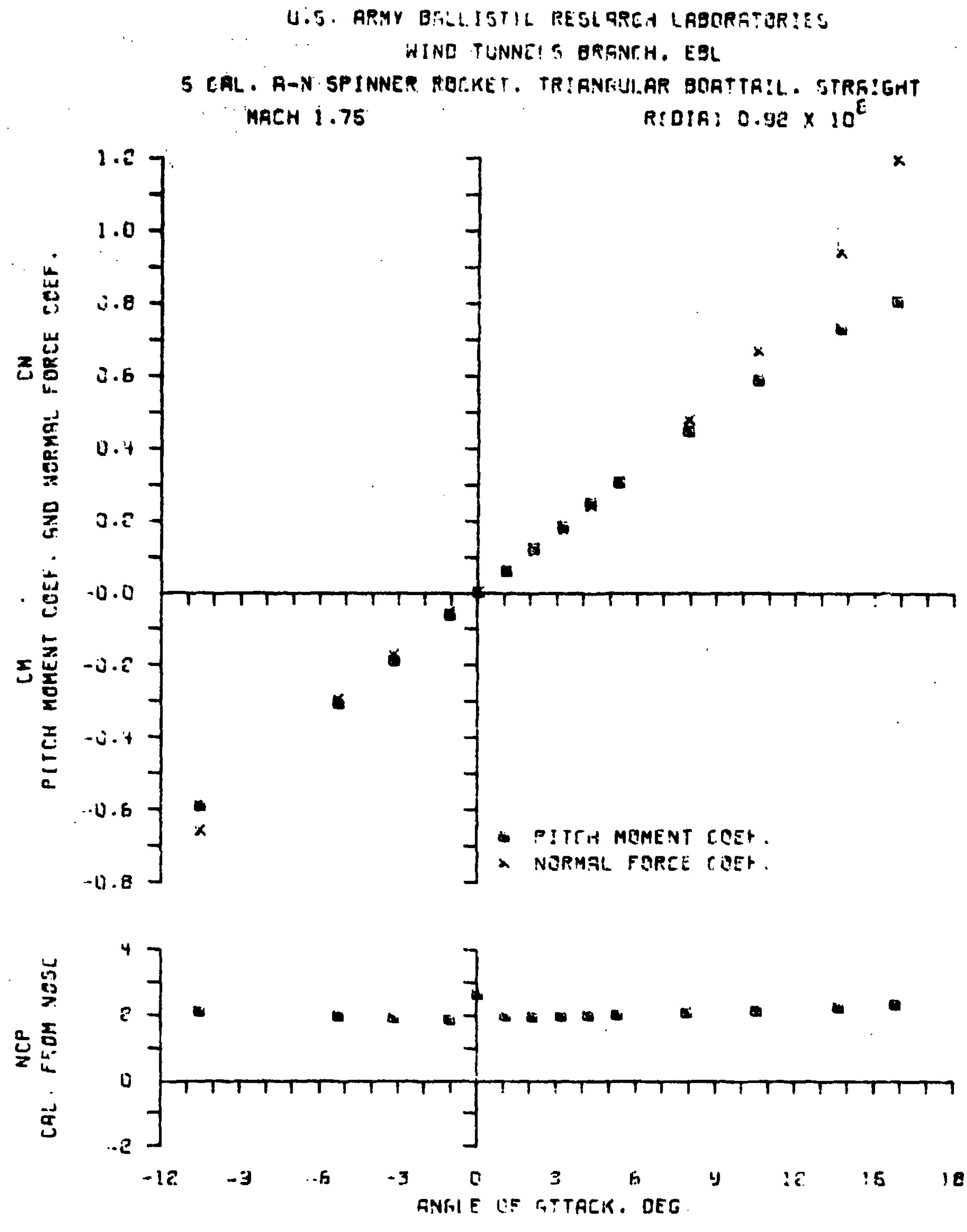
CONFIG= 5.50 RUN= 22.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
NSRDC 7X10 FT. TRANSONIC WIND TUNNEL
5 CAL. A-N SPINNER ROCKET, SQUARE BOATTAIL W/FINS, CANTED
MACH 0.90 PD/V 0.38 R(DIA) 1.40 X 10^6

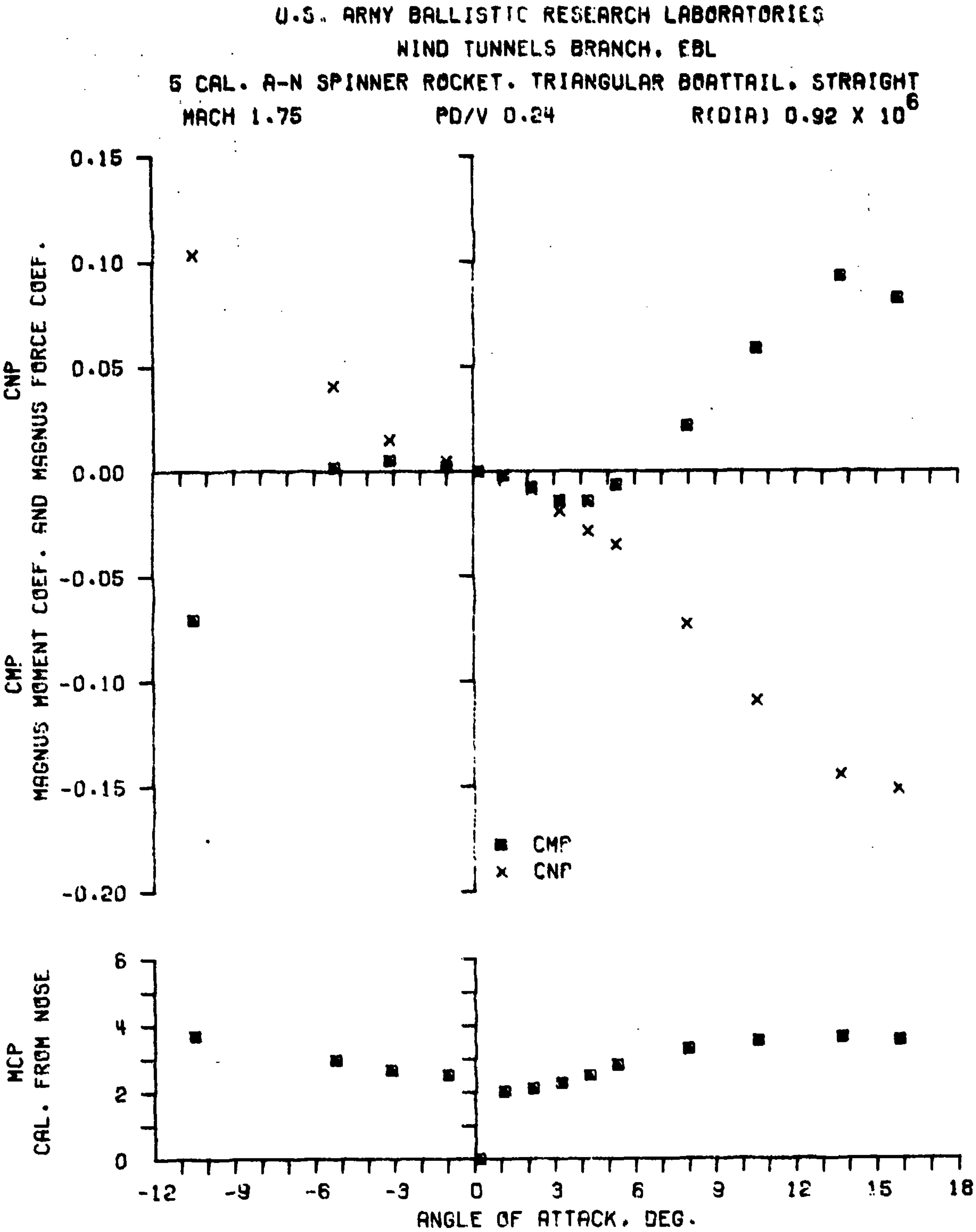


ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG= 5.50 RUN= 22.

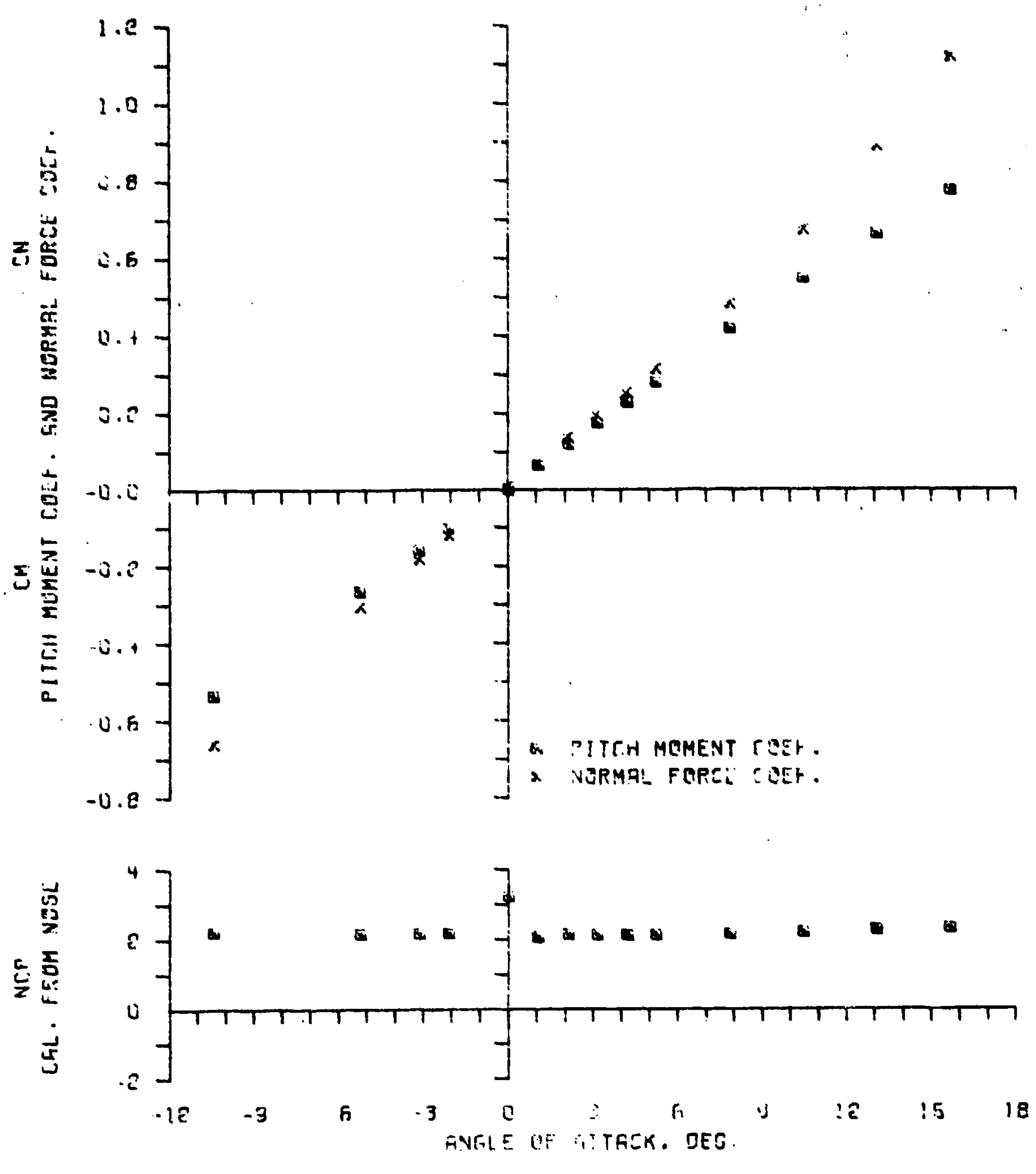


CONFIG= 5.60 RUN= 7.

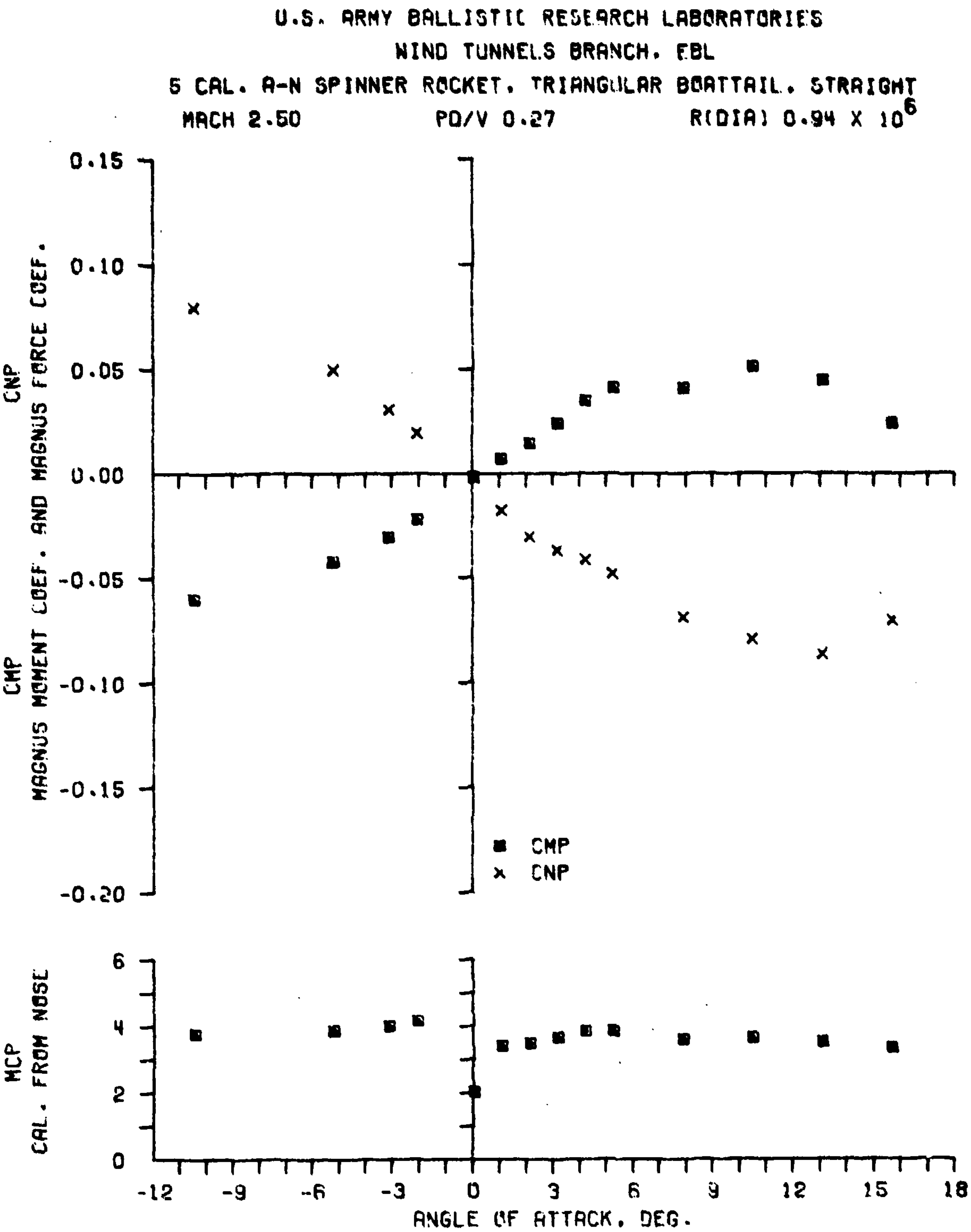


CONFIG= 5.60 RUN= 7.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, BBL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BOATTAIL, STRAIGHT
MACH 2.50 R(DIA) 0.94 X 10^6

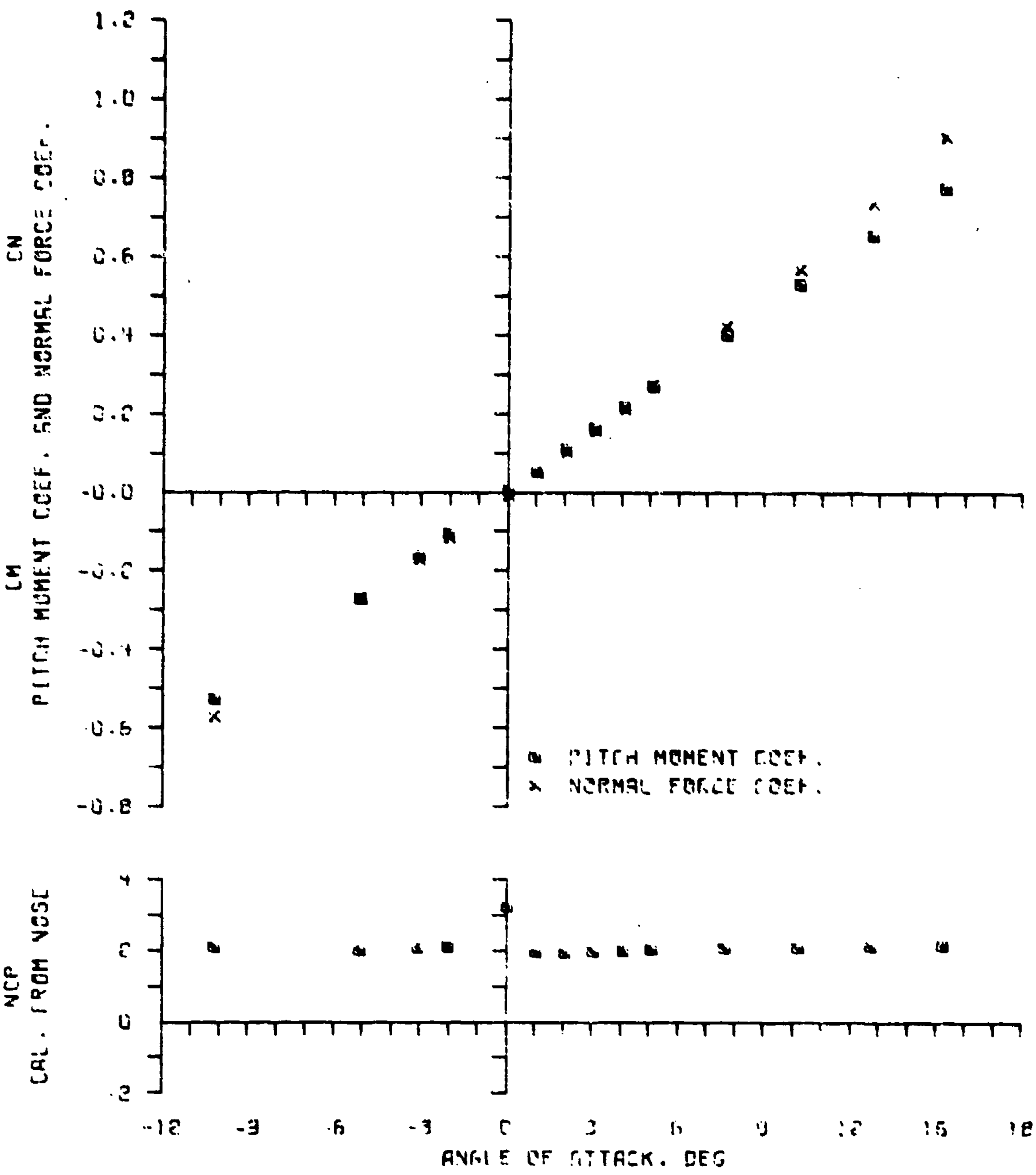


CONFIG= 5.60 RUN= 8.



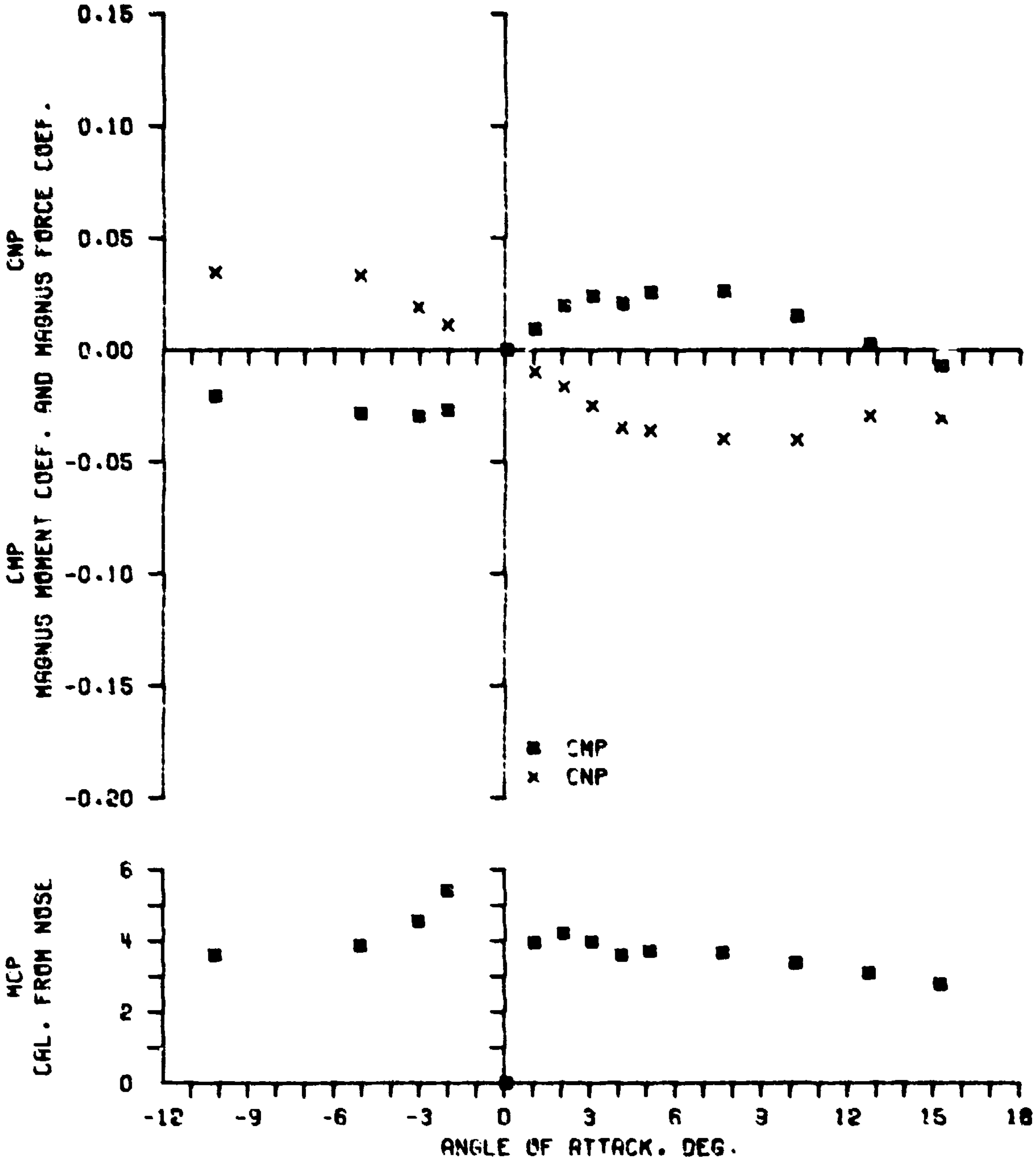
CONFIG= 5.60 RUN= 8.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BOATTAIL, STRAIGHT
MACH 4.00 R(DIA) 0.65 X 10^{6}



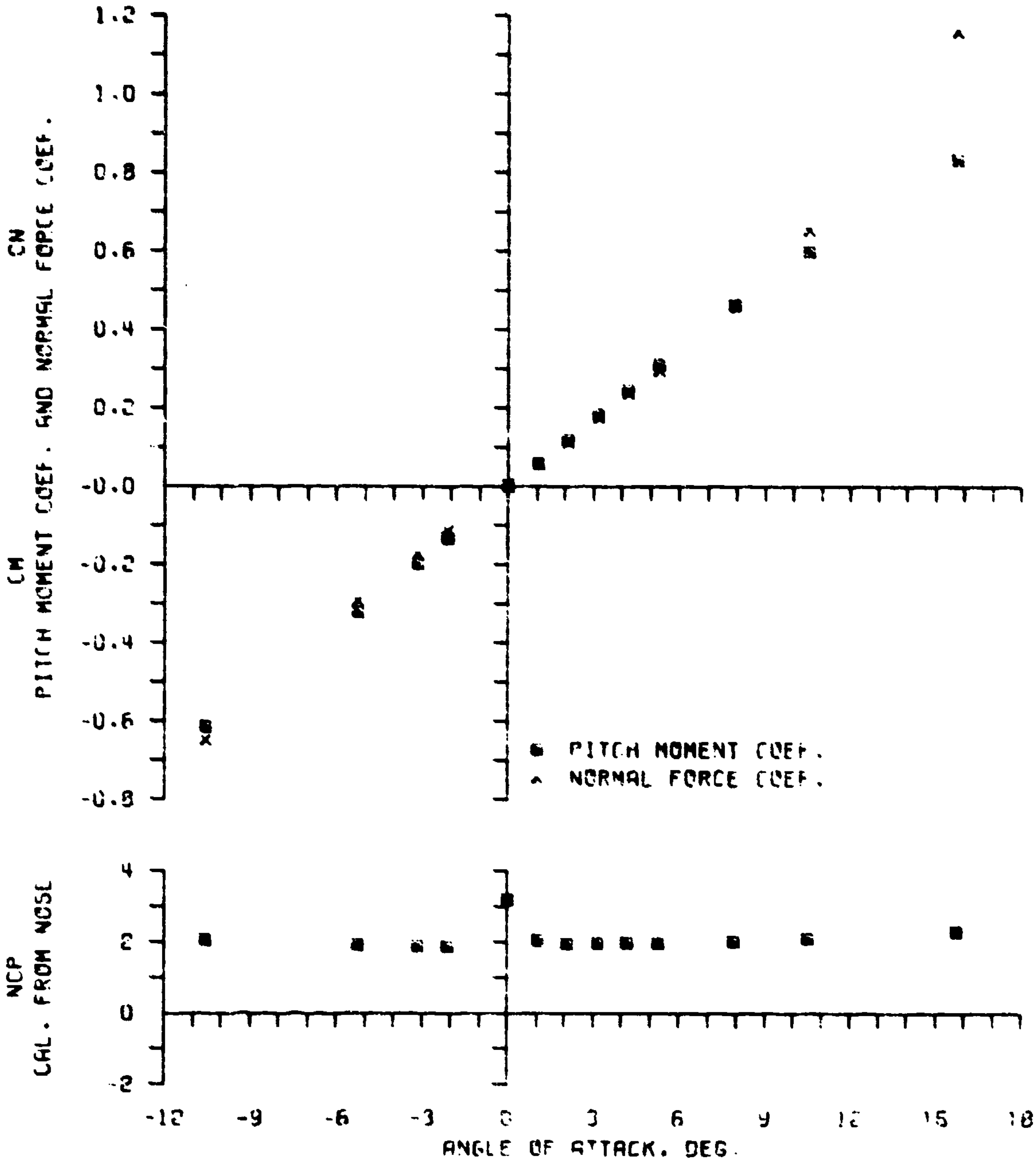
CONFIG= 5.60 RUN= 9.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BOATTAIL, STRAIGHT
MACH 4.00 PD/V 0.24 R(DIA) 0.65 X 10^6

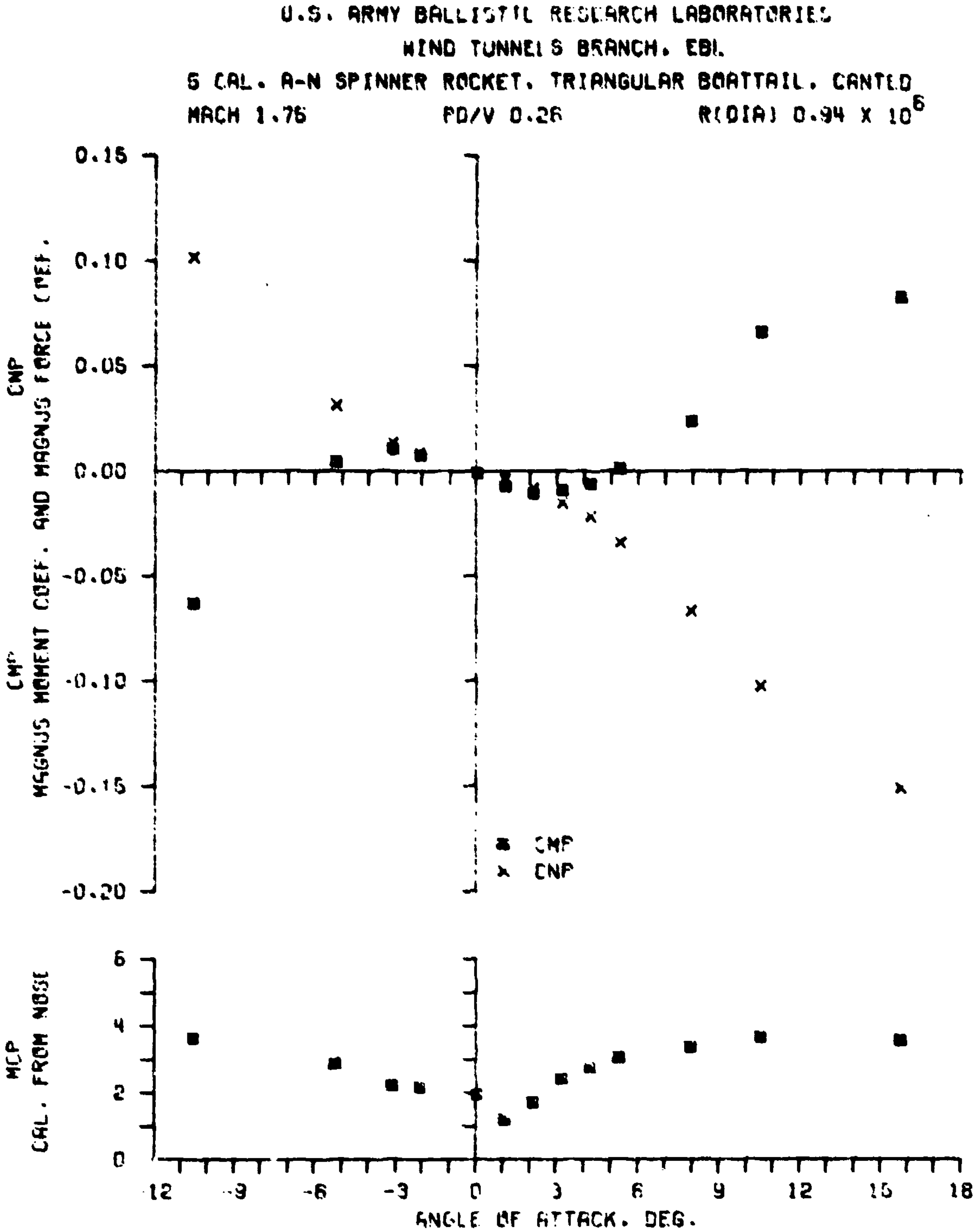


CONFIG= 5.60 RUN= 9.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BOATTAIL, CANTED
MACH 1.75 R(DIA) 0.94 X 10^6



CONFIG= 5.70 RUN= 1.



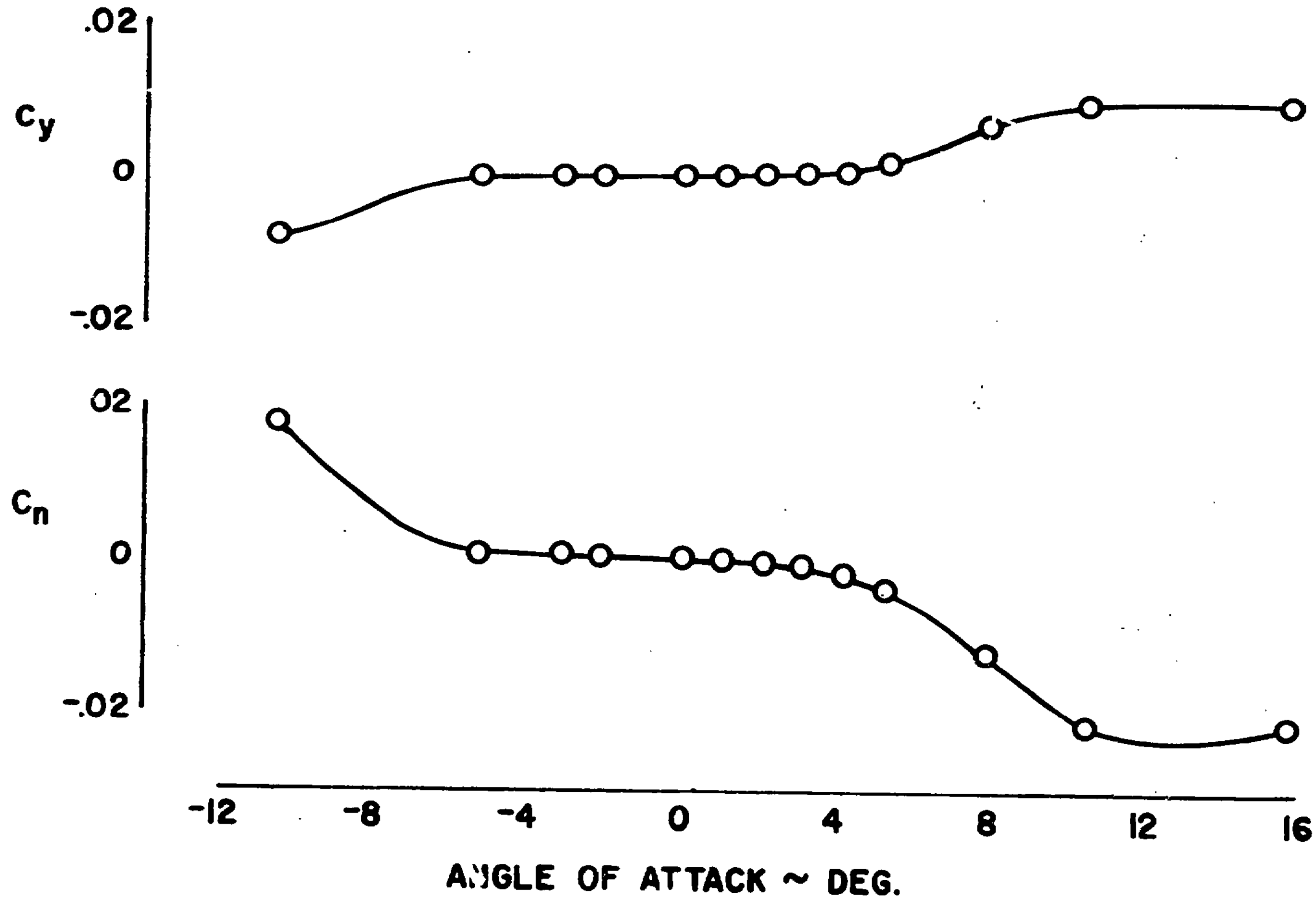
THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND YAWING MOMENT ON NEXT PAGE TO OBTAIN $C_{N_{p_\alpha}}$ AND $C_{m_{p_\alpha}}$.

CONFIG= 5.70 RUN= 1.

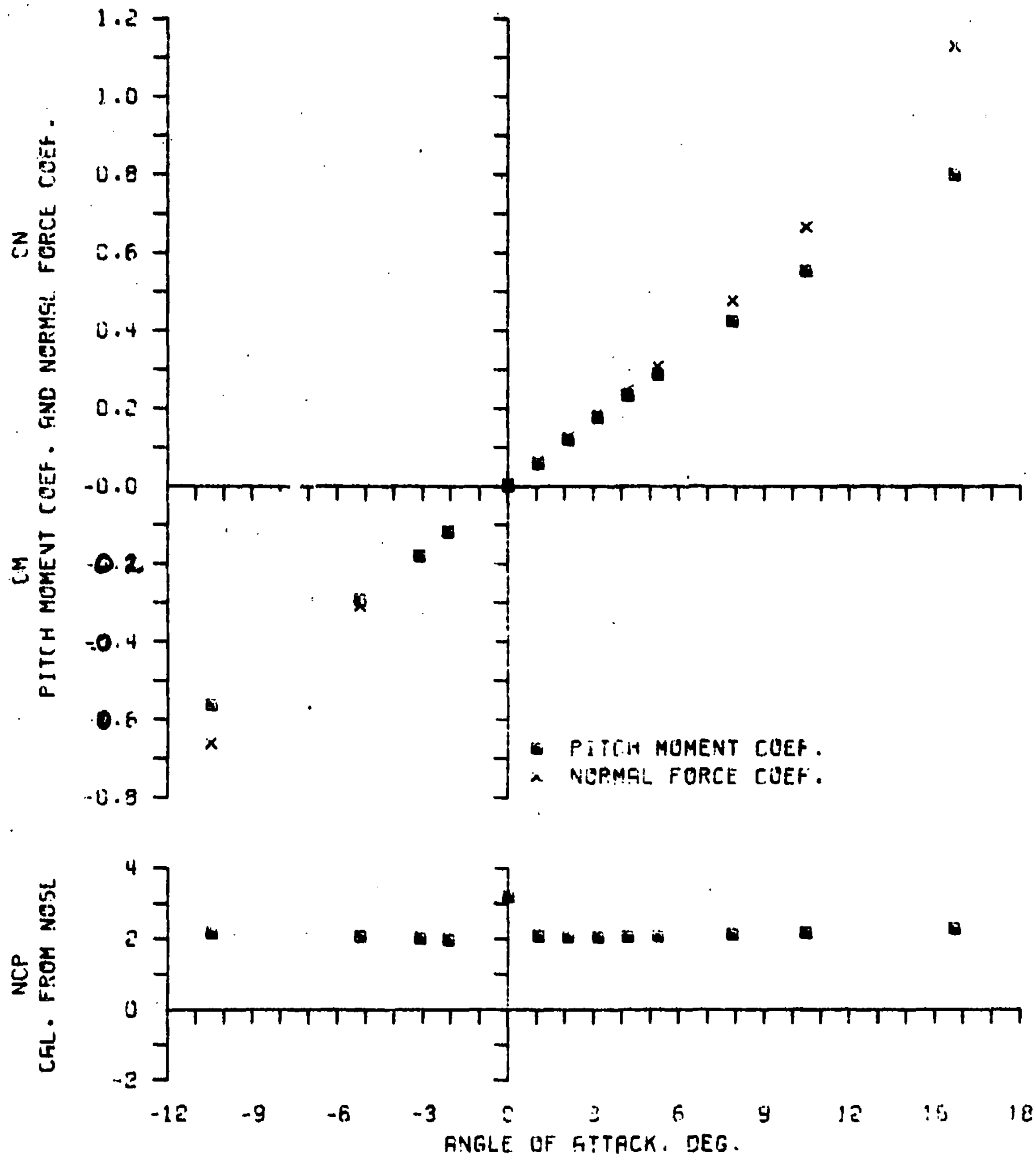
SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Triangular Boattail

Mach 1.75 R_d 0.94 X 10^6

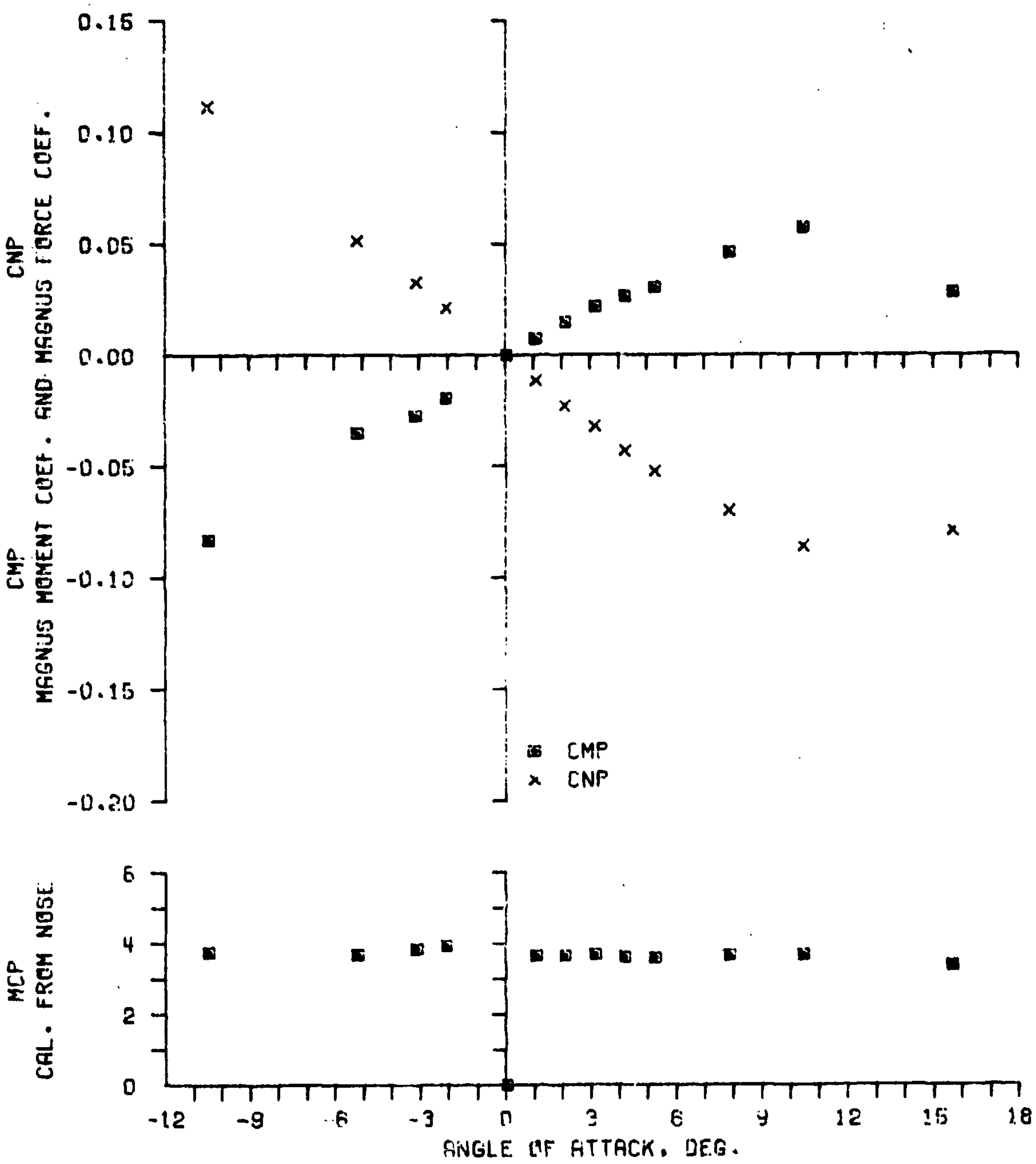


U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH. EBL
5 CAL. A-N SPINNER ROCKET. TRIANGULAR BOATTAIL. CANTED
MACH 2.50 R(DIA) 0.95 X 10^6



CONFIG= 5.70 RUN= 2.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BOATTAIL, CANTED
MACH 2.50 PD/V 0.28 R(DIA) 0.96 X 10^6



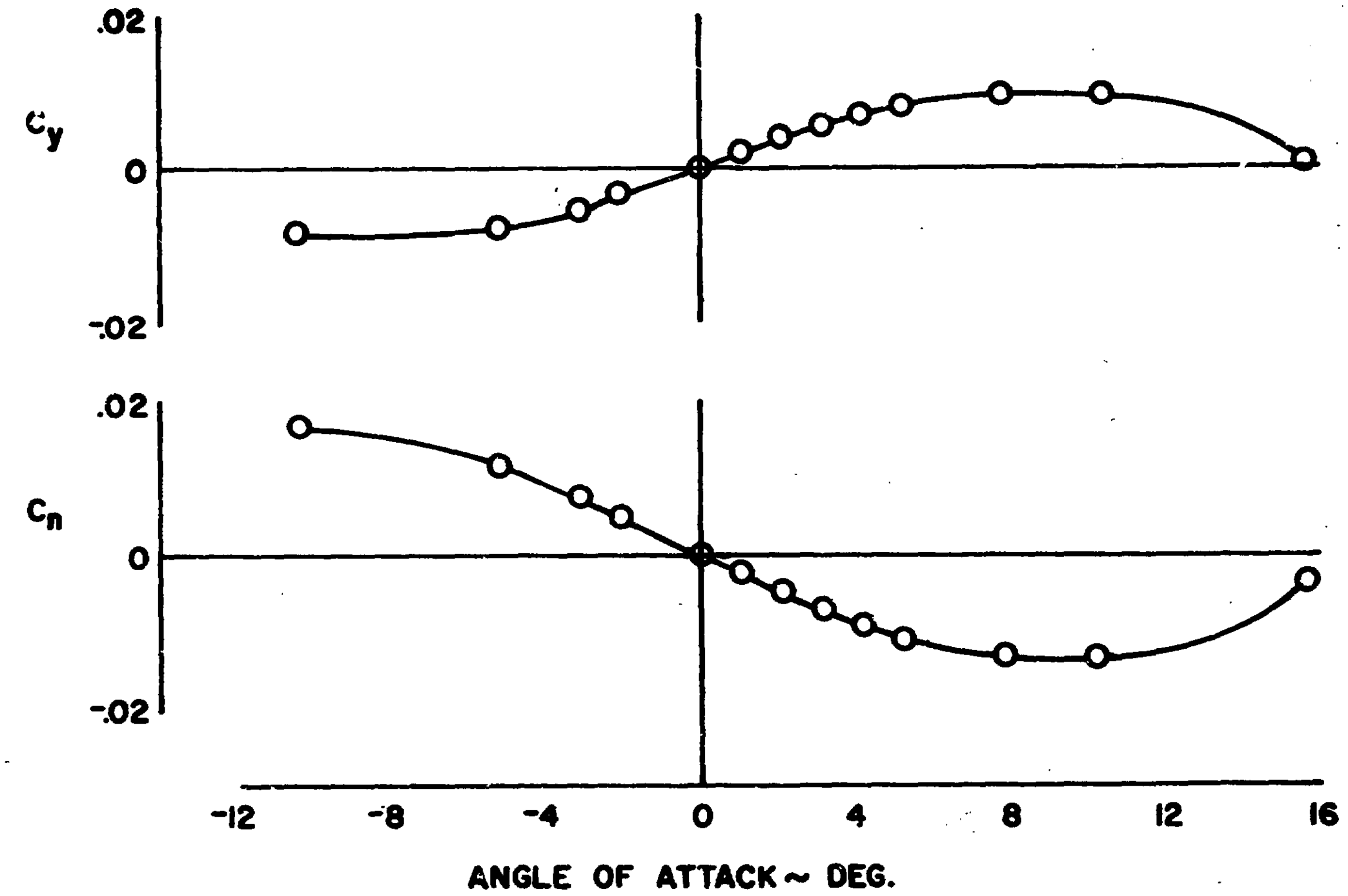
THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND YAWING MOMENT ON NEXT PAGE TO OBTAIN $C_{N_{p_\alpha}}$ AND $C_{m_{p_\alpha}}$.

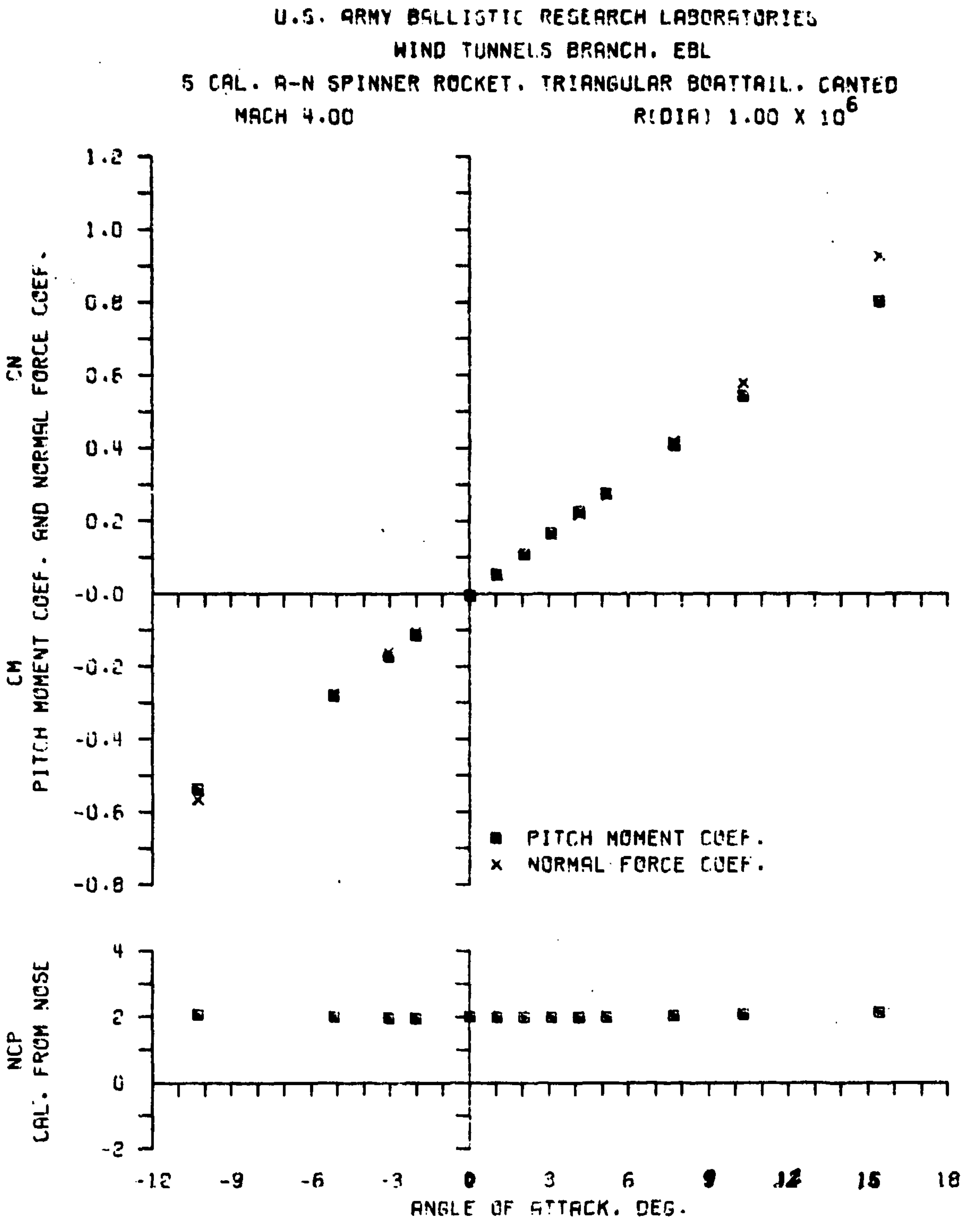
CONFIG= 5.70 RUN= 2.

SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Triangular Boattail

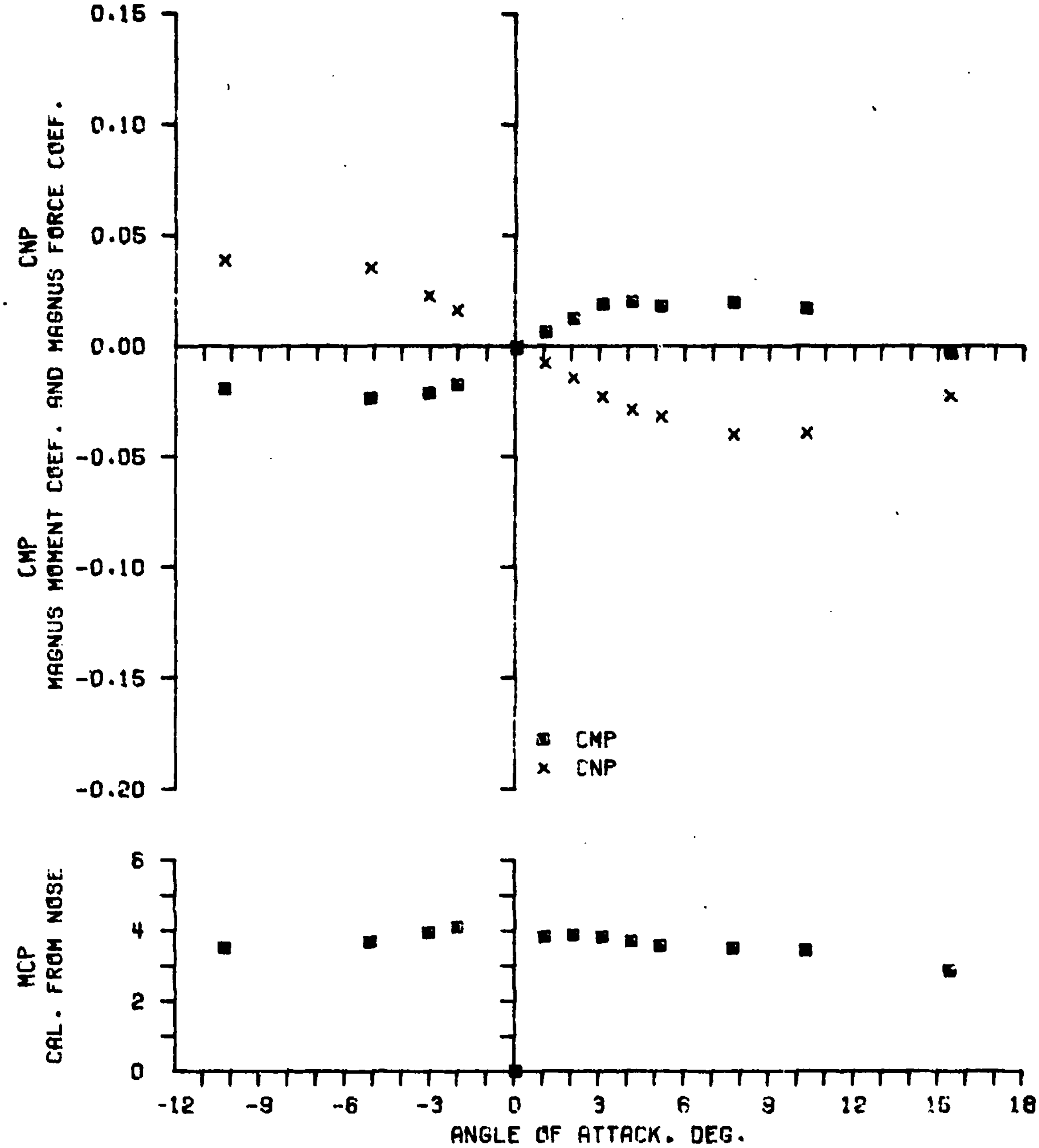
Mach 2.5 R_d 0.95 X 10^6





CONFIG= 5.70 RUN= 3.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, TRIANGULAR BOATTAIL, CANTED
MACH 4.00 PD/V 0.18 R(DIA) 1.00 X 10^6



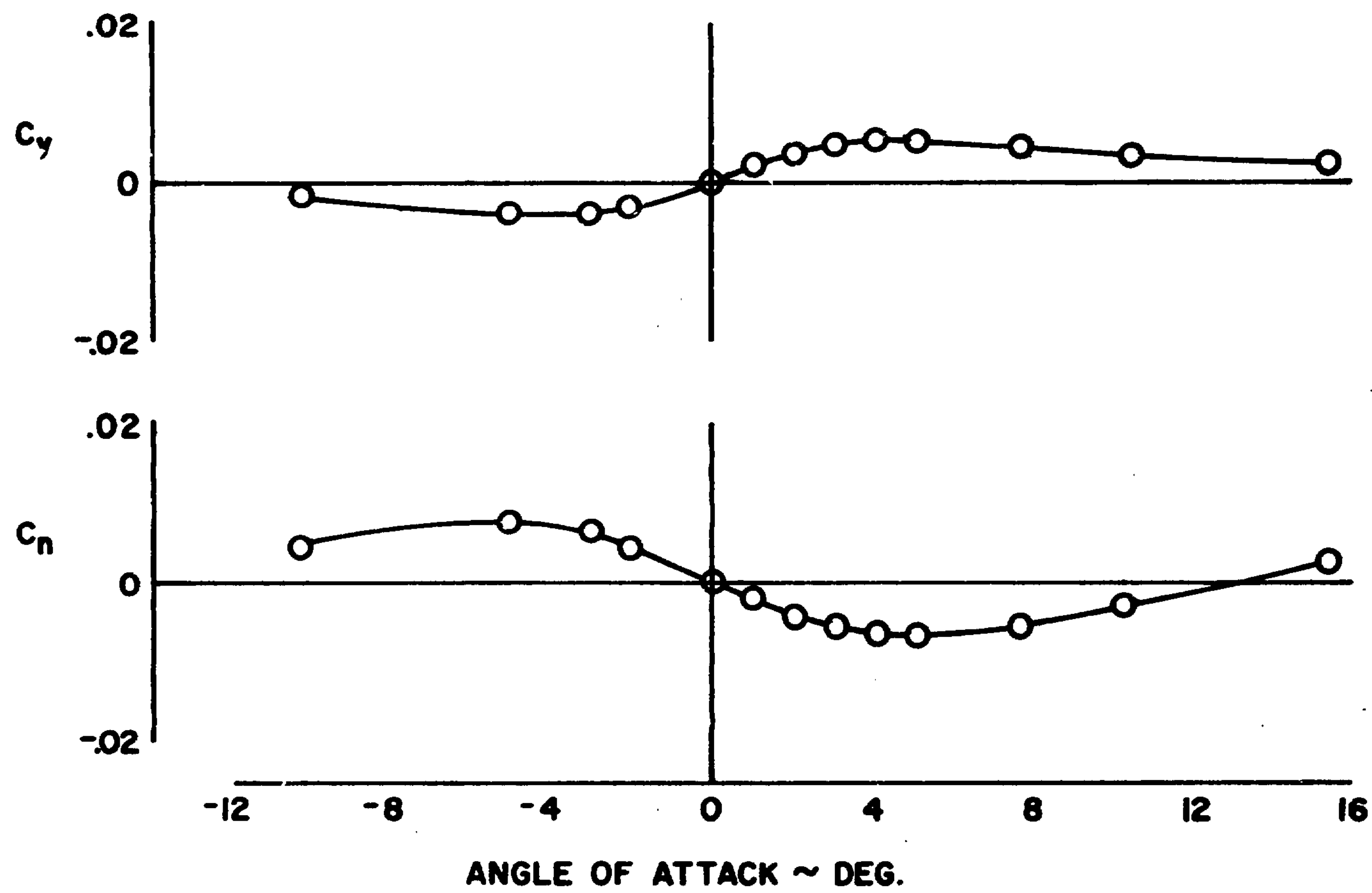
THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND YAWING MOMENT ON NEXT PAGE TO OBTAIN $C_{N_{p_\alpha}}$ AND $C_{m_{p_\alpha}}$.

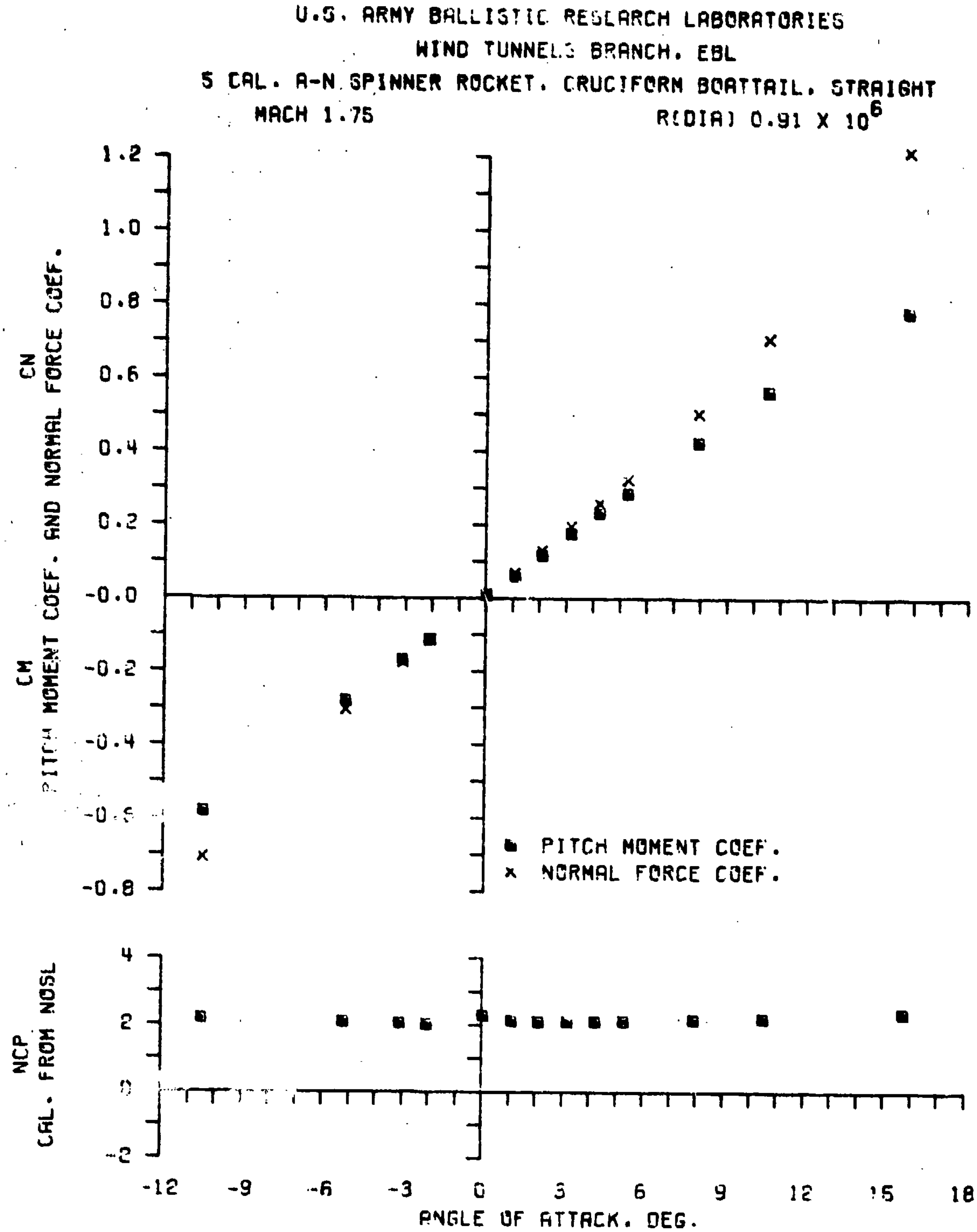
CONFIG= 5.70 RUN= 3.

SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Triangular Boattail

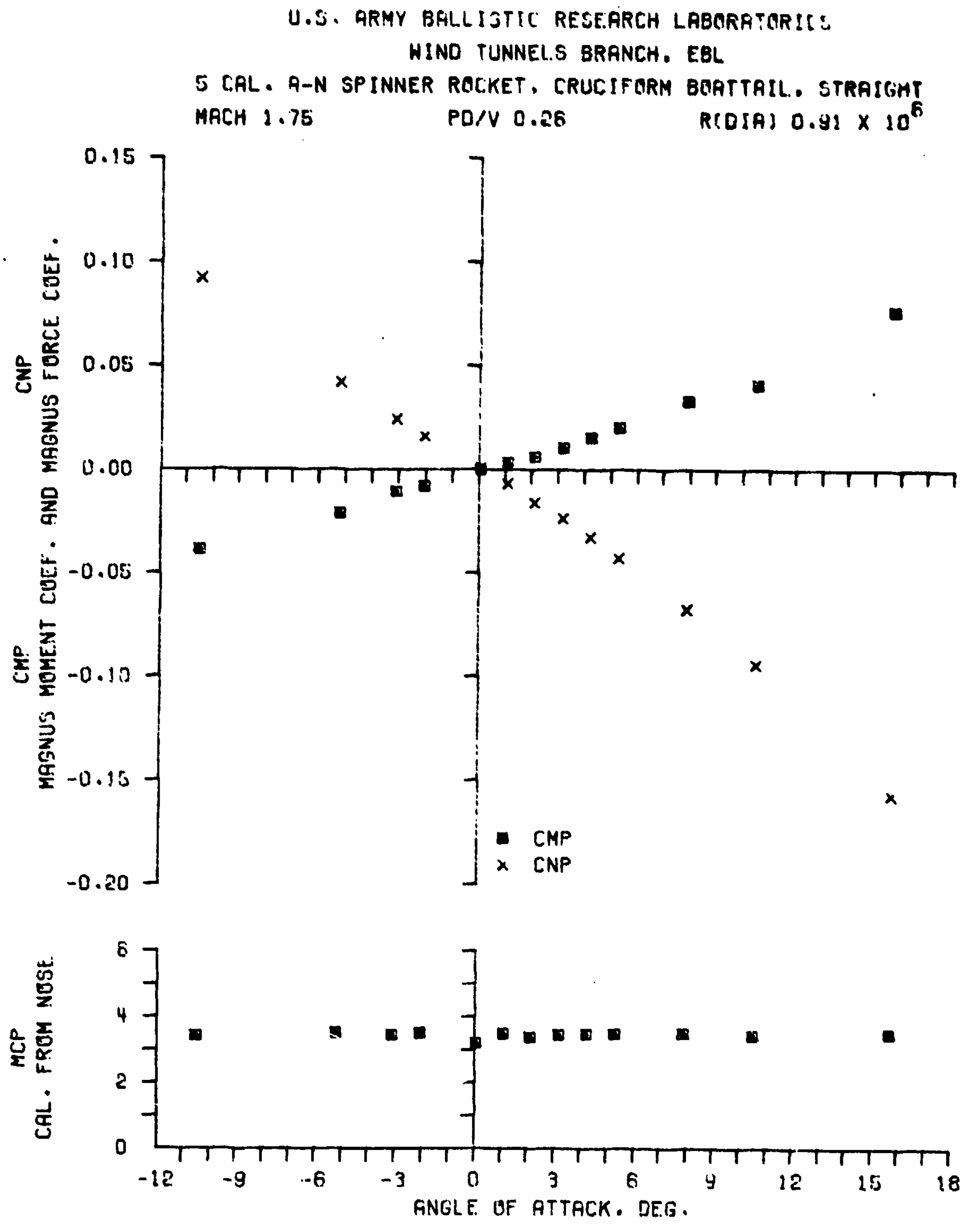
Mach 4.0 R_d 1 X 10^6



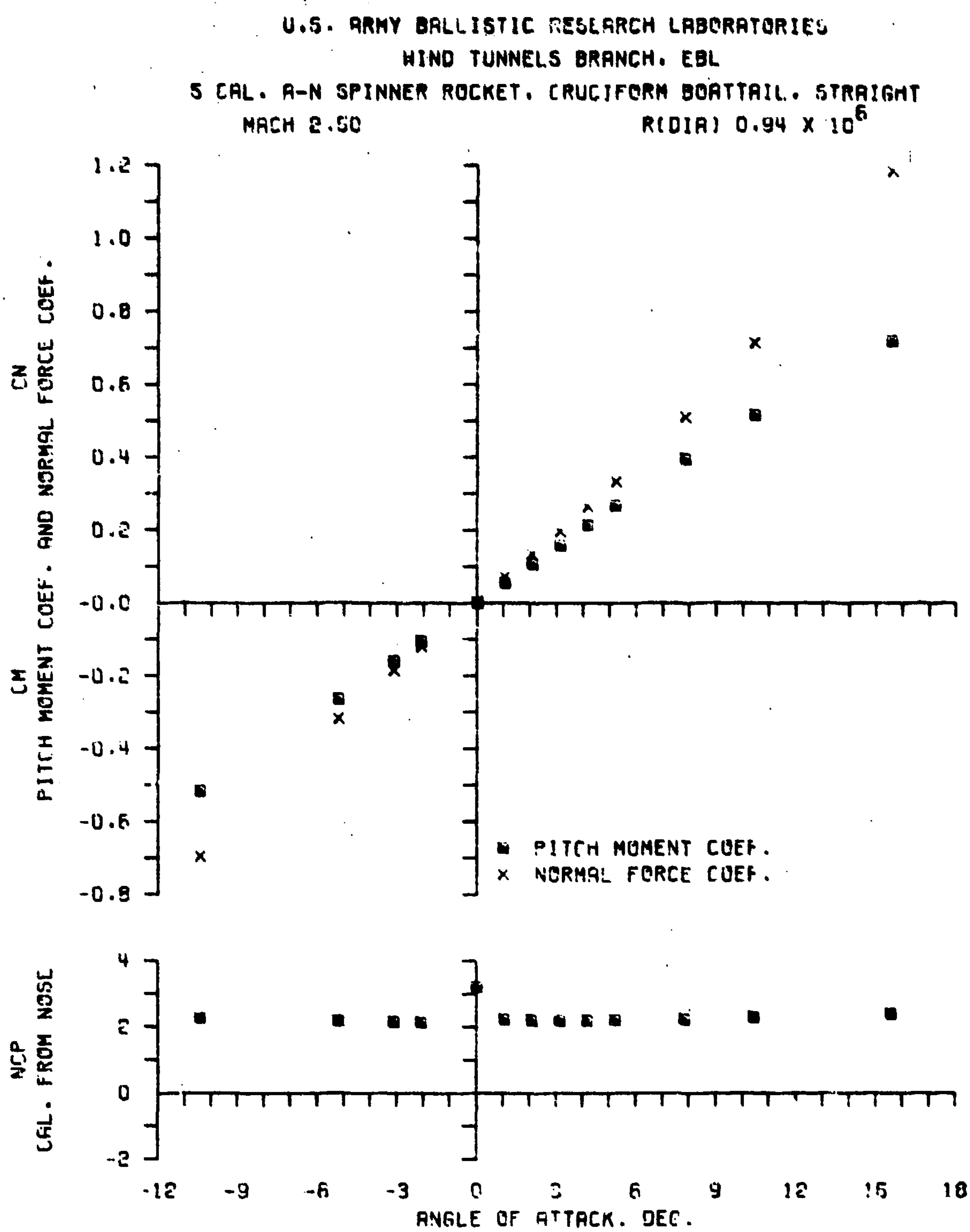


CONFIG= 5.90 RUN= 13.

147

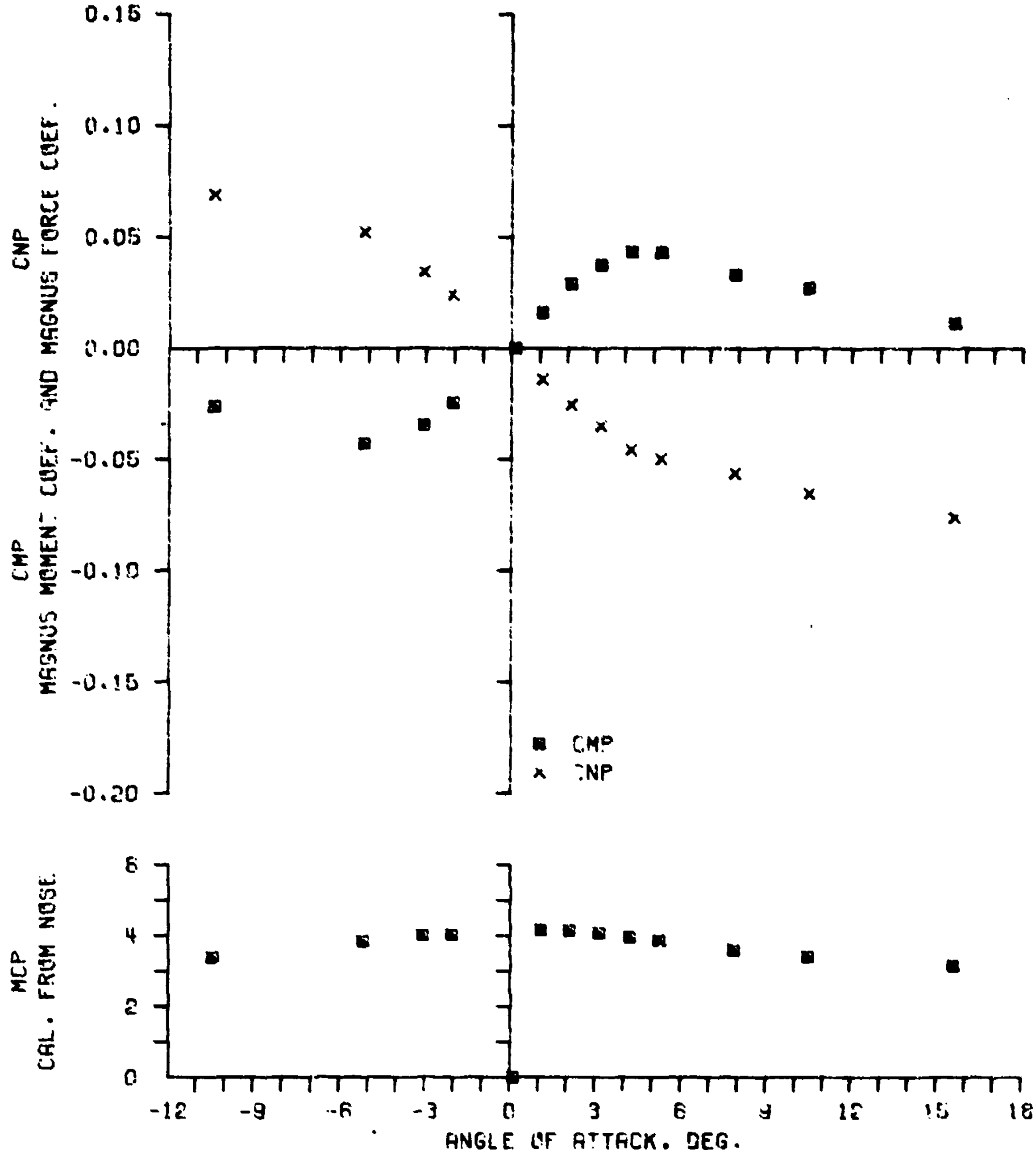


CONFIG= 5.90 RUN= 13.



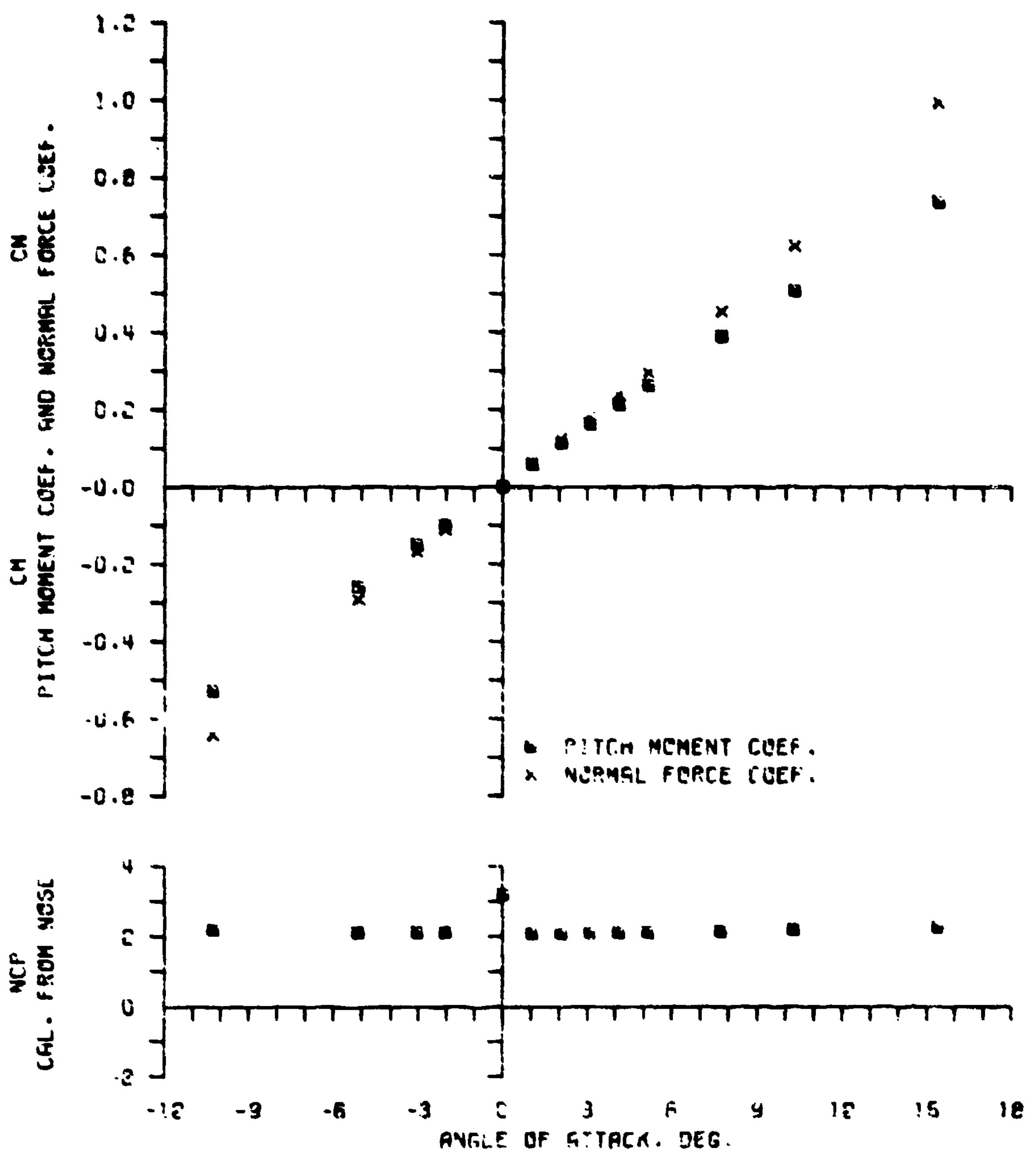
CONFIG= 5.90 RUN= 14.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, STRAIGHT
MACH 2.50 PD/V 0.21 R(DIA) 0.94 X 10^6



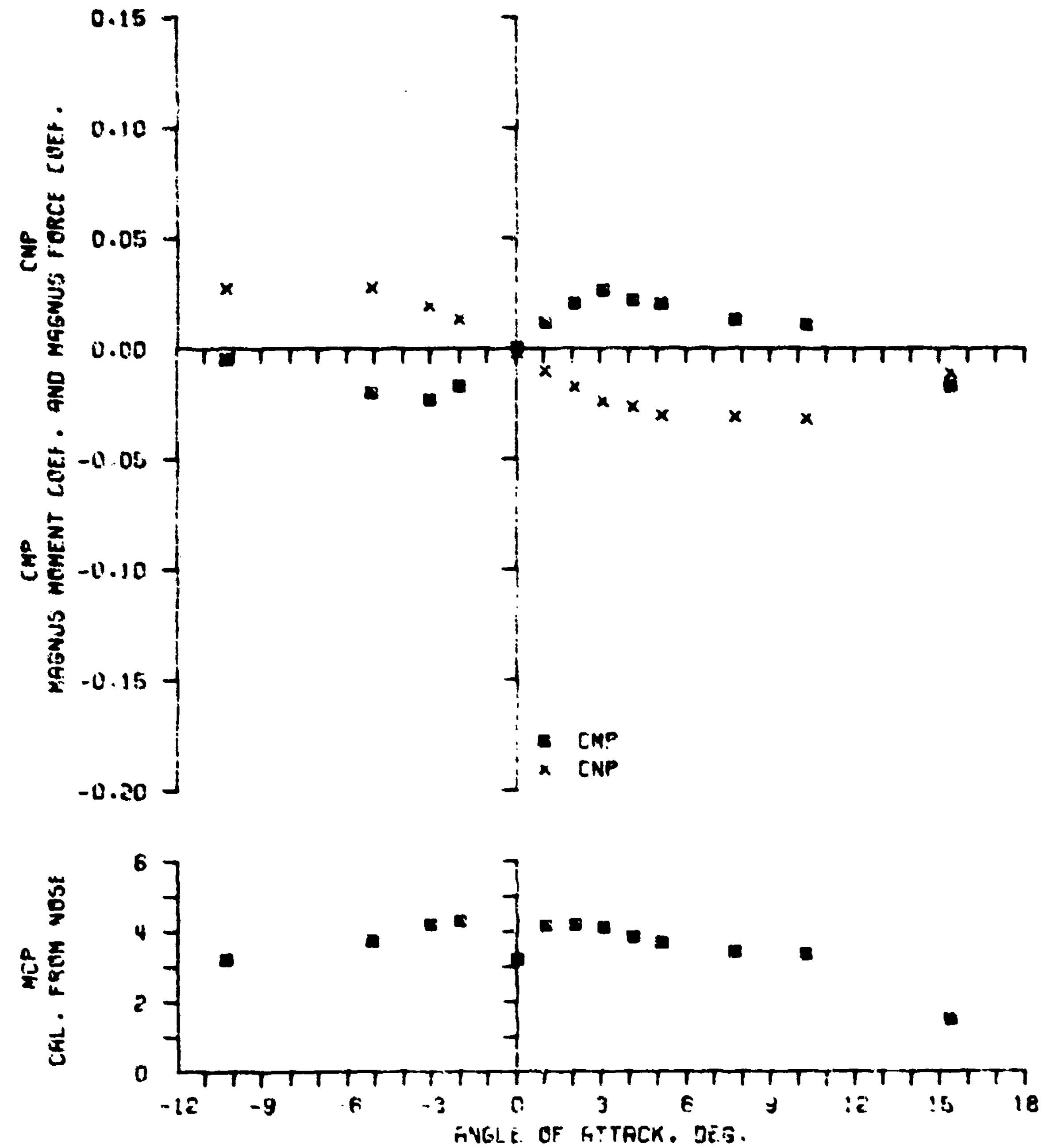
CONFIG= 5.90 RUN= 14.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, STRAIGHT
MACH 4.00 R(DIA) 0.99 X 10^6



CONFIG= 5.90 RUN= 15.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, STRAIGHT
MACH 4.00 PD/V 0.18 R(DIA) 0.99 X 10^6



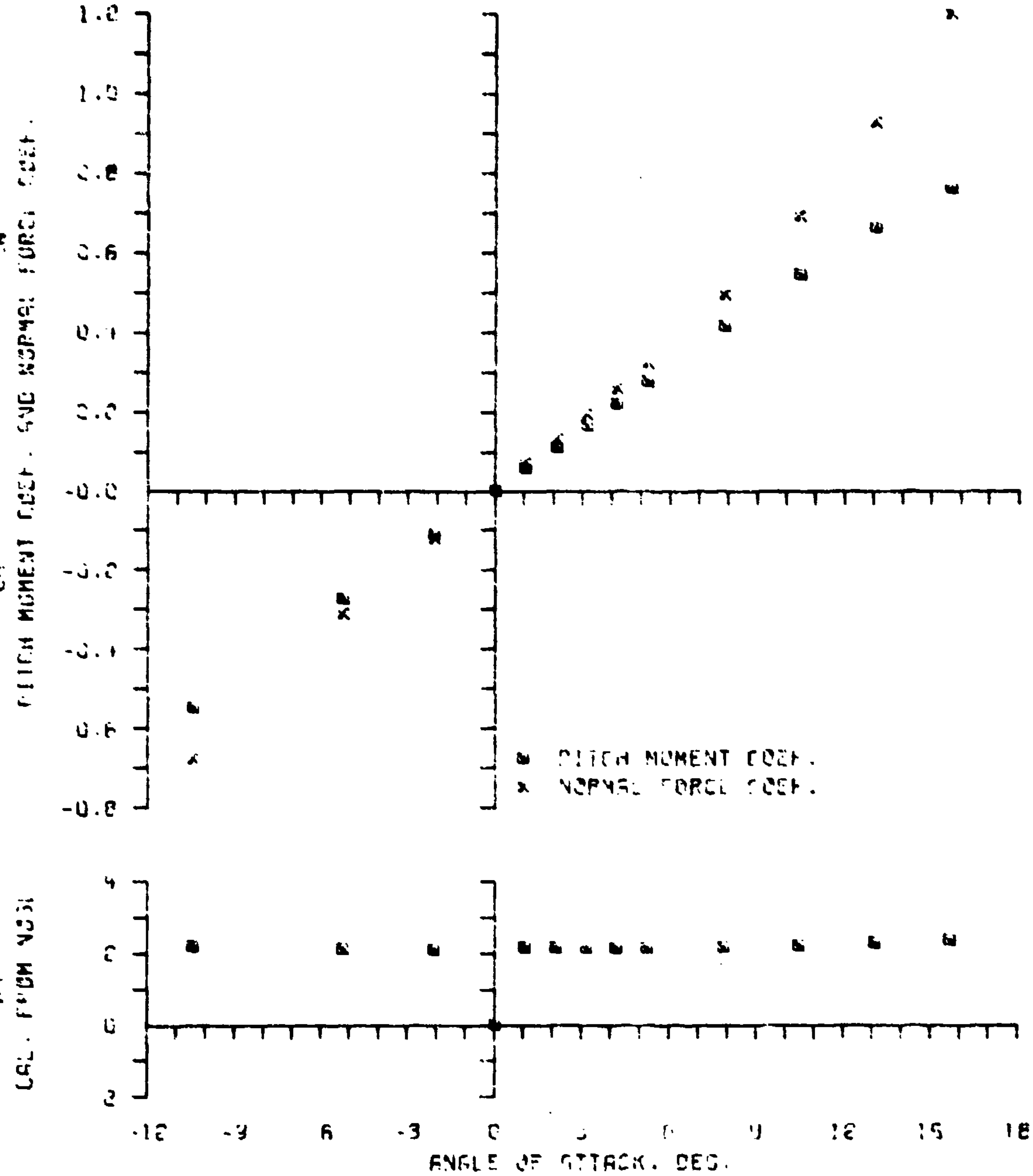
CONFIG= 5.90 RUN= 15.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES

WIND TUNNELS BRANCH, BRL

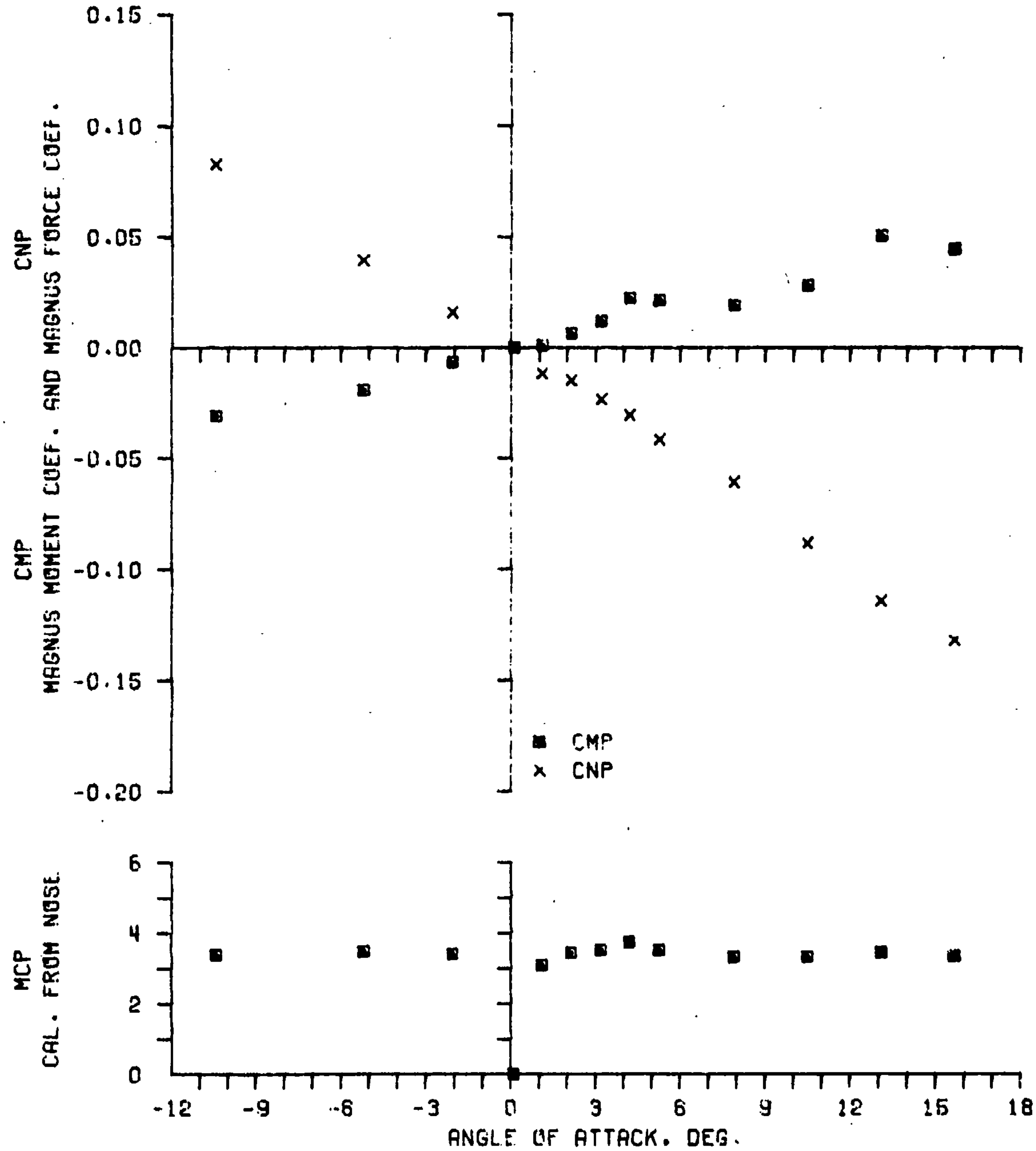
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, CANTED

MACH 1.75 RE(DIA) 0.82 X 10^6



CONFIG= 5.00 RUN= 4.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, CANTED
MACH 1.75 PD/V 0.26 R(DIA) 0.82 X 10^6



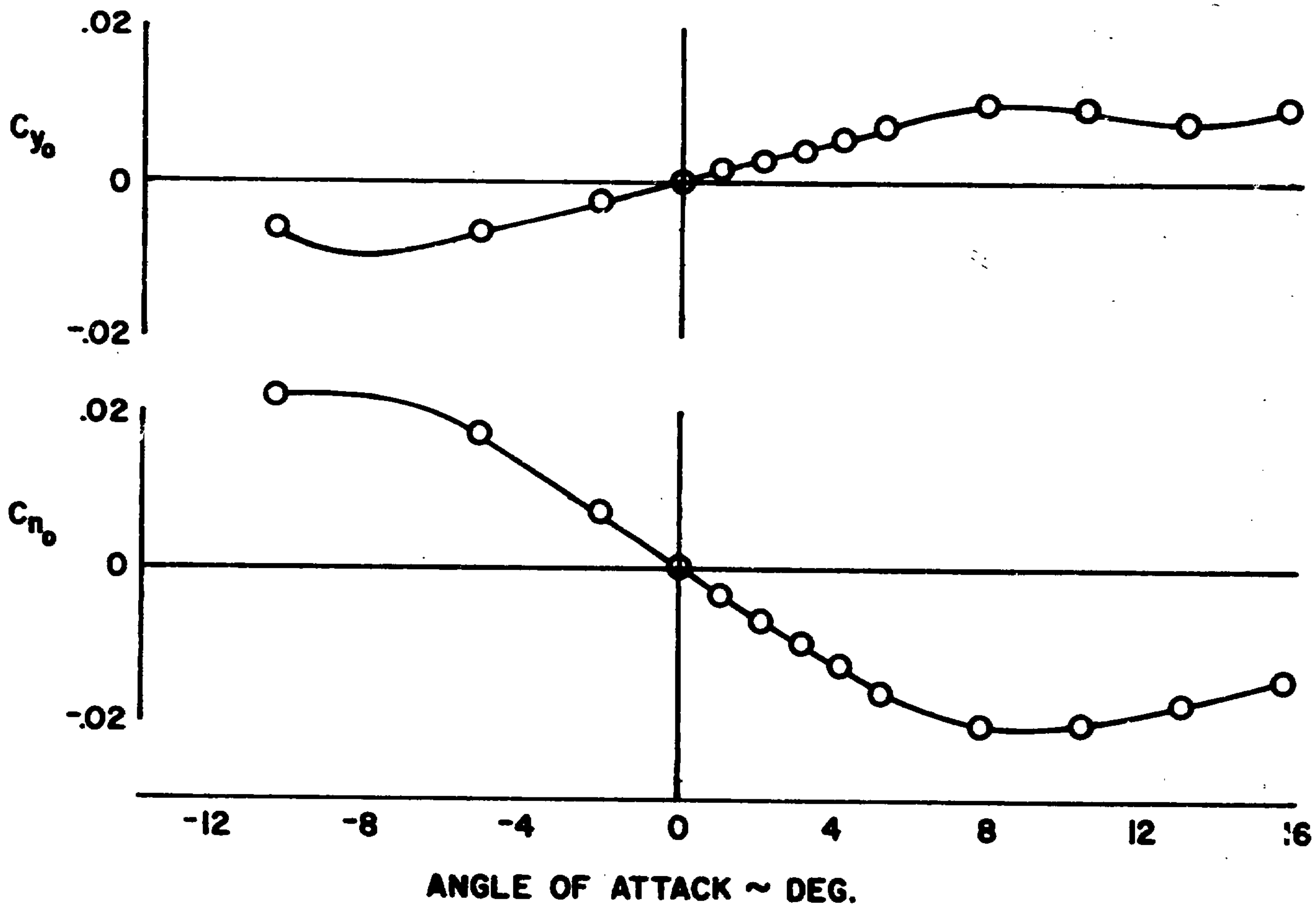
THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND YAWING MOMENT ON NEXT PAGE TO OBTAIN $C_{N_{p_\alpha}}$ AND $C_{m_{p_\alpha}}$.

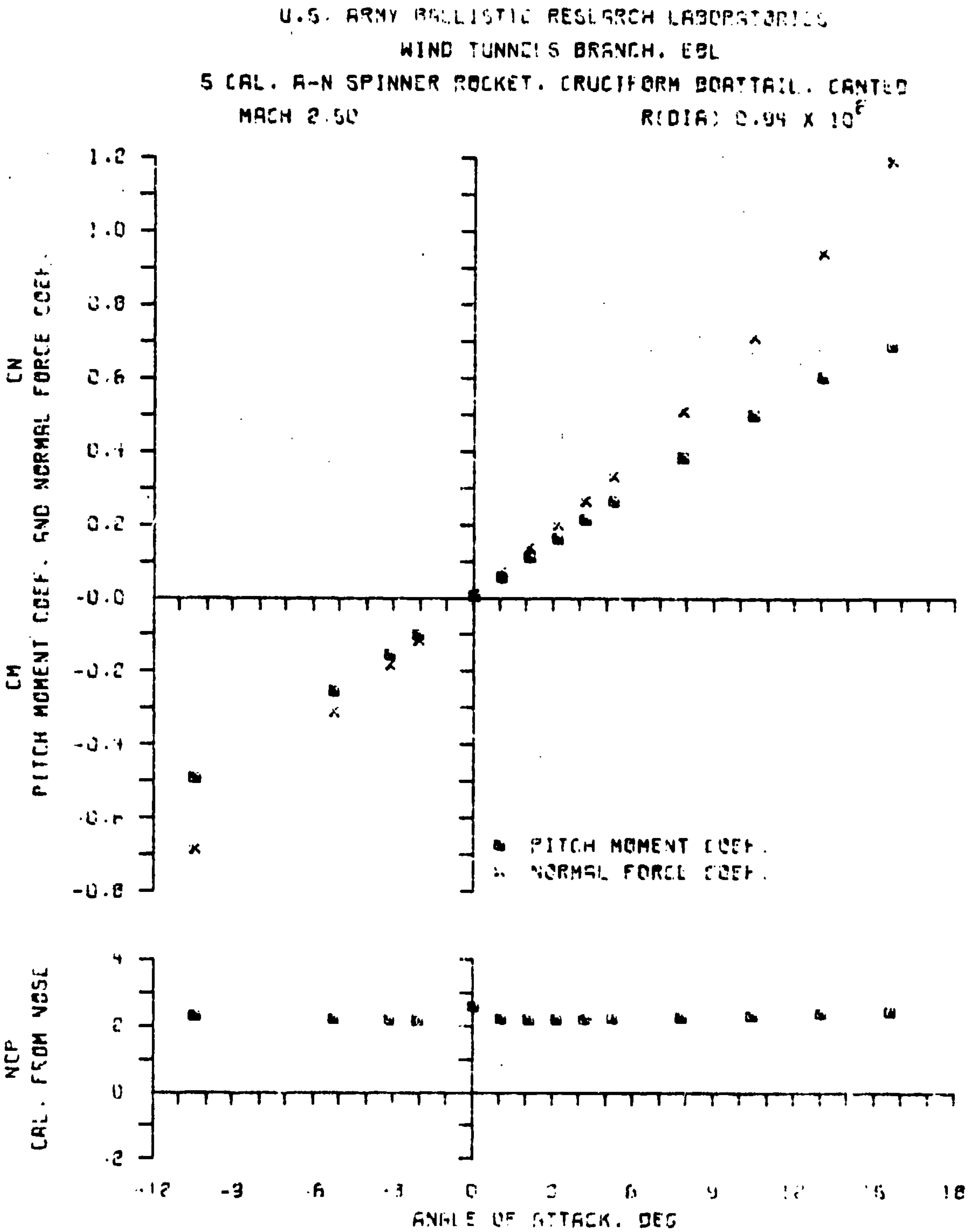
CONFIG= 5.90 RUN= 4.

SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Cruciform Boattail

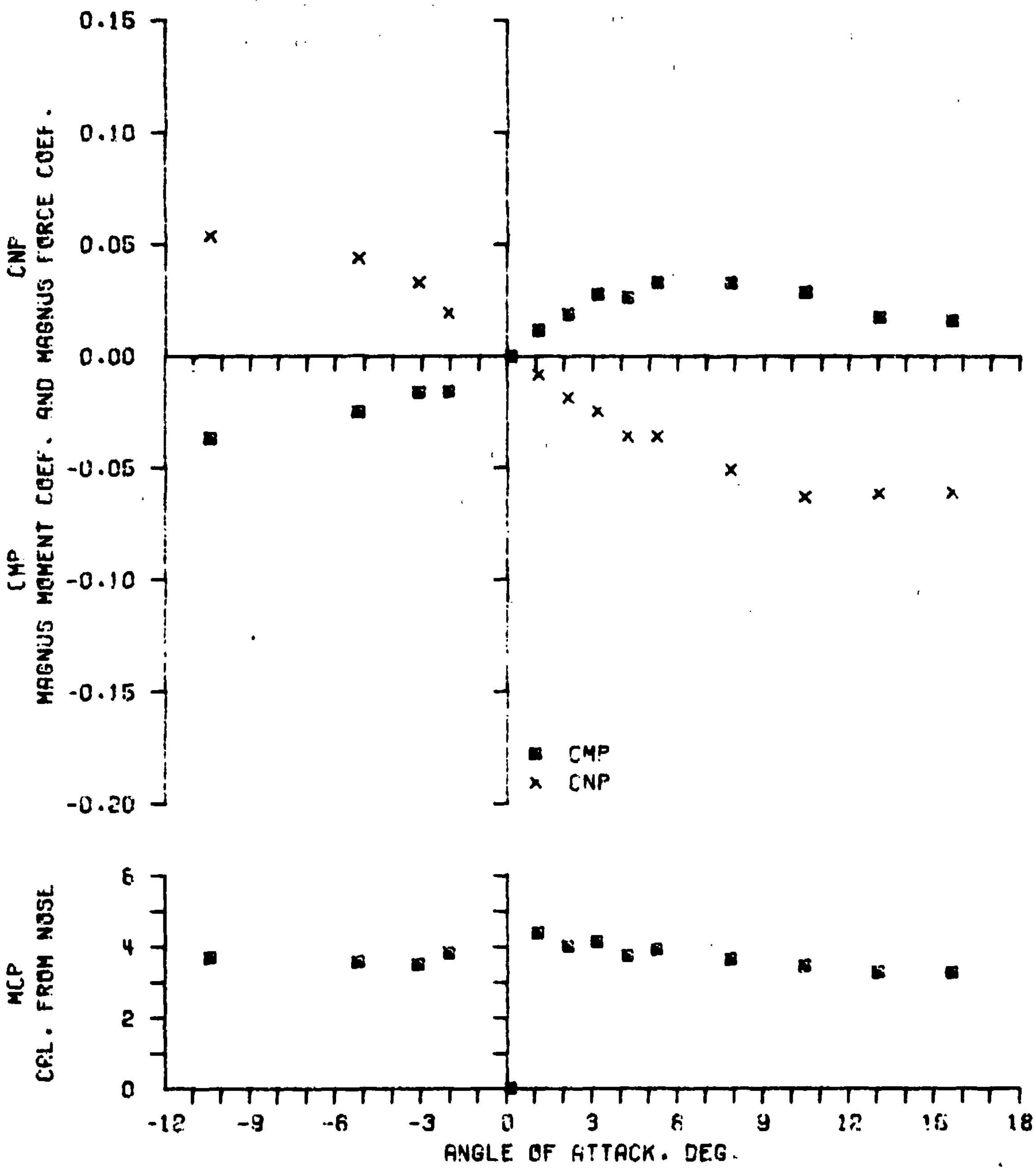
Mach 1.75 R_d 0.82 X 10^6





CONFIG 5.90 RUN= 5.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, CANTED
MACH 2.50 PD/V 0.21 R(DIA) 0.94 X 10^6



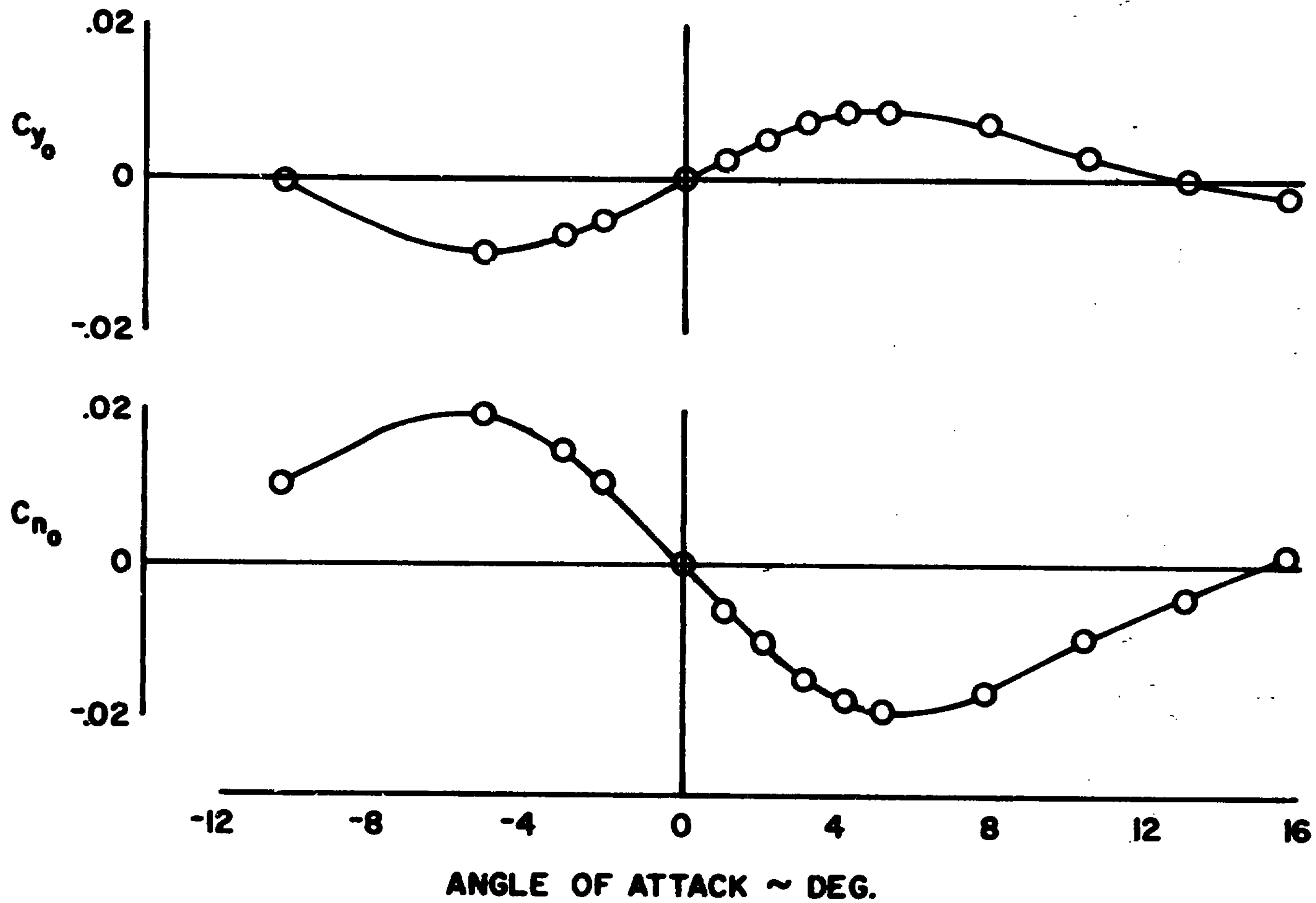
THESE DATA MUST BE COMBINED WITH ZERO SPIN SIDE FORCE AND YAWING MOMENT ON NEXT PAGE TO OBTAIN $C_{N_{p_\alpha}}$ AND $C_{m_{p_\alpha}}$.

CONFIG= 5.90 RUN= 5.

SIDE FORCE AND YAWING MOMENT AT ZERO SPIN

5 cal. A-N with Canted Cruciform Boattail

Mach 2.50 R_d 0.94 X 10^6

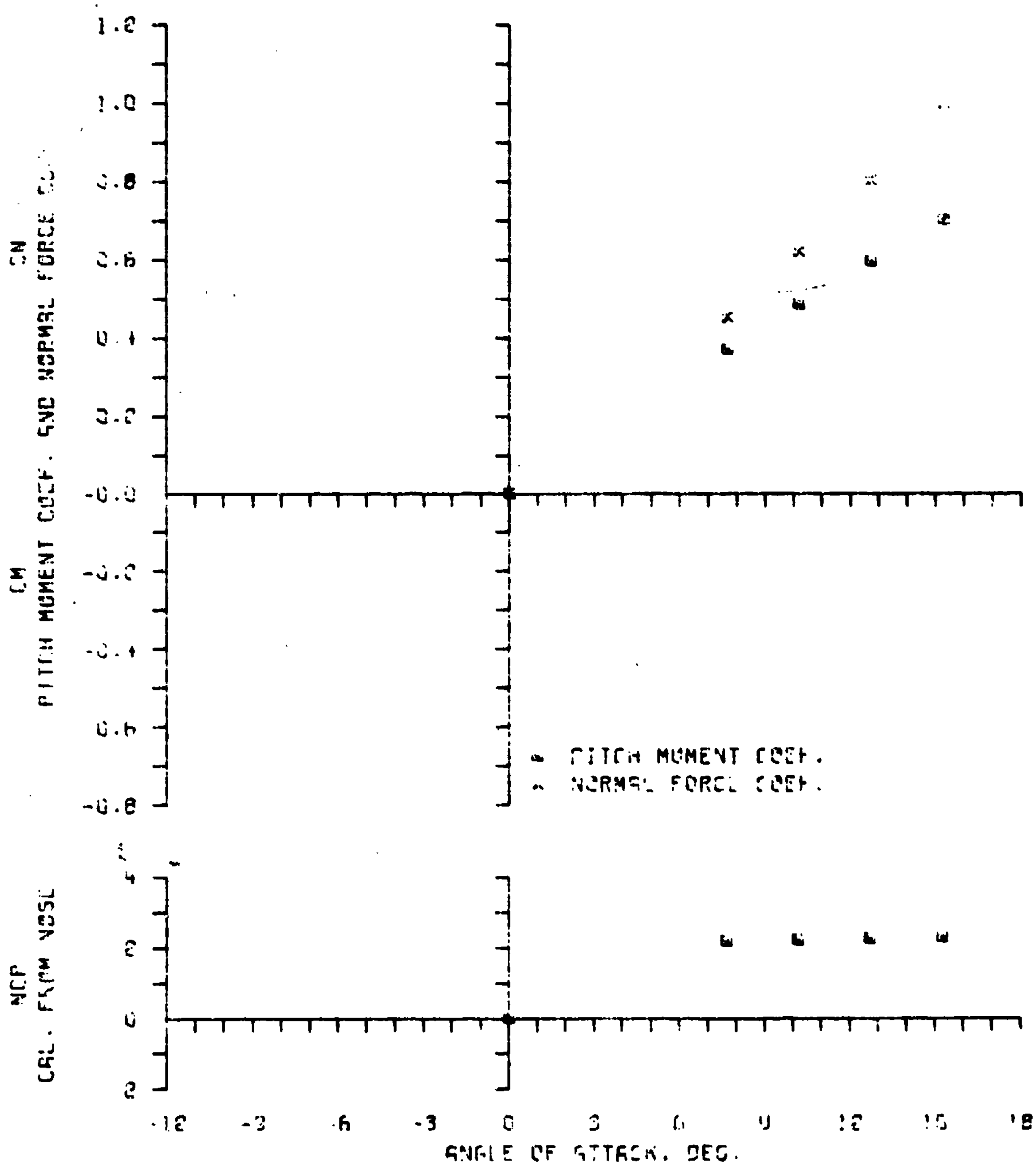


U.S. ARMY BALLISTIC RESEARCH LABORATORIES

WIND TUNNELS BRANCH, BRL

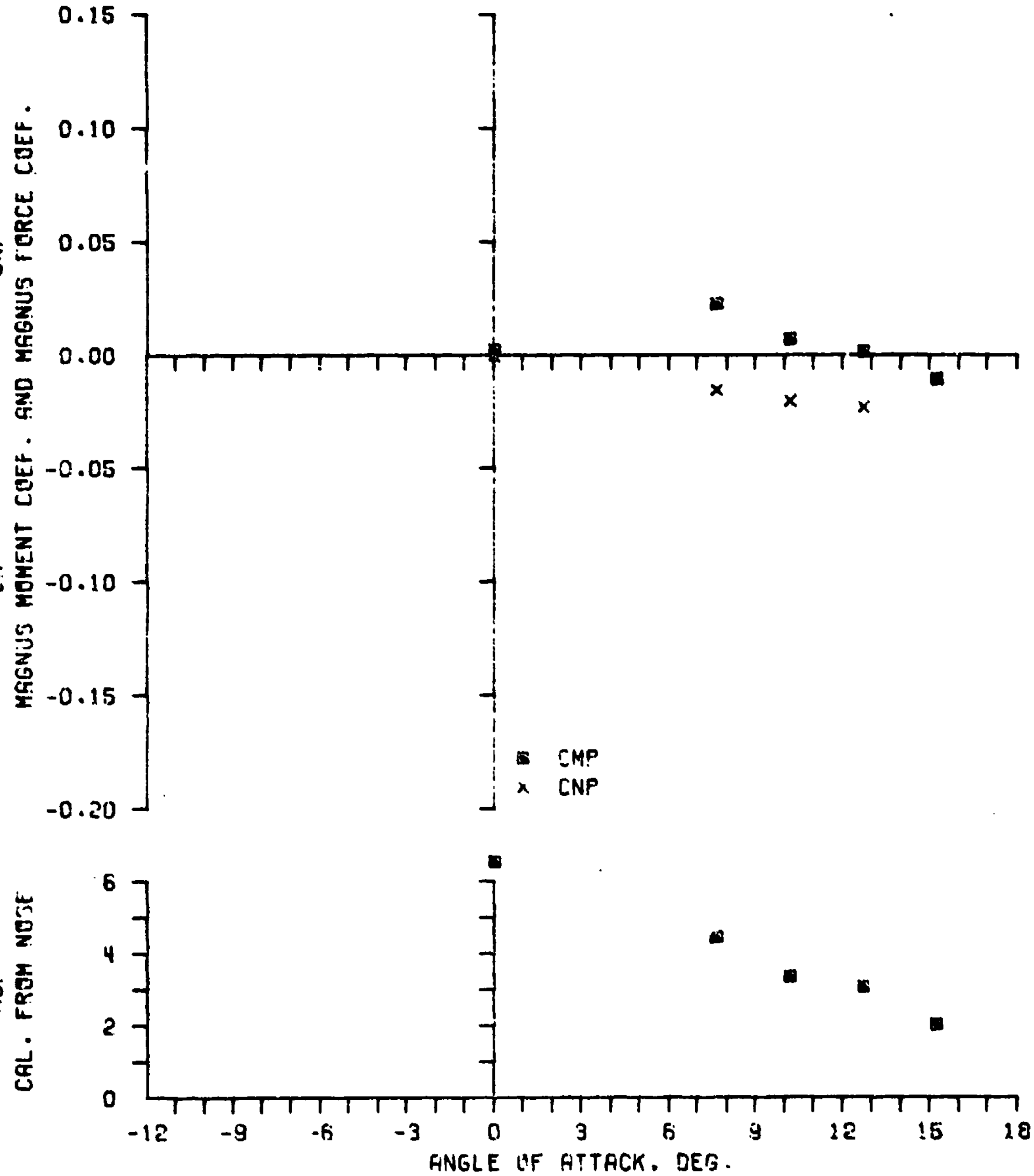
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, CANTED

MACH 4.03 R(DIA) 0.65 X 10^6



CONFIG= 5.90 RUN= 6.

U.S. ARMY BALLISTIC RESEARCH LABORATORIES
WIND TUNNELS BRANCH, EBL
5 CAL. A-N SPINNER ROCKET, CRUCIFORM BOATTAIL, CANTED
MACH 4.00 PD/V 0.18 R(DIA) 0.65 X 10^6



ZERO SPIN SIDE FORCE AND YAWING MOMENT NOT OBTAINED.

CONFIG= 5.90 RUN= 6.

LIST OF SYMBOLS

C_D — $\dfrac{\text{Drag}}{\frac{1}{2}\rho V^2 S}$ positive direction is aft

C_{D_o} — zero angle of attack drag coefficient

$C_{D_{\alpha}2}$ — drag coefficient slope due to angle of attack (from $C_D = C_{D_o} + C_{D_{\alpha}2}\,\alpha^2$)

C_{ℓ_p} — roll damping moment coefficient--negative moment tends to decrease spin

C_{ℓ_δ} — roll moment coefficient due to fin cant--positive moment tends to increase spin

C_m — $\dfrac{\text{Pitching Moment}}{\frac{1}{2}\rho V^2 S d}$ moment center is .6 ℓ calibers from nose. Positive moment is due to positive normal force ahead of the moment center.

C_{m_α} — $\dfrac{d\,C_m}{d\,\alpha}$ at $\alpha = 0°$ per radian

C_{m_p} — $\dfrac{\text{Magnus Moment}}{\frac{1}{2}\rho V^2 S d \frac{pd}{V}}$ moment center is .6 ℓ calibers from nose. Positive moment is due to positive Magnus force ahead of moment center.

$C_{m_{p_\alpha}}$ — $\dfrac{d\,C_{m_p}}{d\,\alpha}$ at $\alpha = 0°$ per radian

$C_{m_q} + C_{m_{\dot\alpha}}$ — $\dfrac{\text{Damping Moment}}{\frac{1}{2}\rho V^2 S d \frac{q_t d}{V}}$

C_N — $\dfrac{\text{Normal Force}}{\frac{1}{2}\rho V^2 S}$ positive direction is up

C_{N_α} — $\dfrac{d\,C_N}{d\,\alpha}$ at $\alpha = 0°$ per radian

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C_{N_p}	$\dfrac{\text{Magnus Force}}{\frac{1}{2}\rho V^2 S \frac{pd}{V}}$ positive direction is to right looking upstream
$C_{N_{p_\alpha}}$	$\dfrac{d\, C_{N_p}}{d\, \alpha}$ at $\alpha = 0°$ per radian
C_{n_o}	Magnus or side moment at zero spin
C_{Y_o}	Magnus or side force at zero spin
d	body diameter and reference length
I_x	axial moment of inertia
I_y	transverse moment of inertia
k_x	axial radius of gyration
k_y	transverse radius of gyration
M_{CP}	Magnus force center of pressure
N_{CP}	normal force center of pressure
p	body axial spin rate, rad/sec (positive is clockwise looking upstream)
q_t	complex transverse angular velocity
R_d	Reynolds number based on d
S	body area $= \dfrac{\pi d^2}{4}$
S_d	dynamic stability $= \dfrac{2\,(C_{L_\alpha} + k_x^{-2}\, C_{m_{p_\alpha}})}{C_{L_\alpha} - C_D - k_y^{-2}\,(C_{m_q} + C_{m_{\dot{\alpha}}})}$

LIST OF SYMBOLS (Continued)

S_g gyroscopic stability $= \dfrac{\left(\dfrac{I_x}{I_y}\ \dfrac{pd}{V}\right)^2}{\dfrac{2\rho S d^3}{I_y}\ C_{m_\alpha}}$

V free stream velocity

α angle of attack

δ cant angle of fin or twisted surface

ρ free stream air density

$$\delta_\Gamma\, C_{\ell_\delta} + \frac{pd}{V}\, C_{\ell_p} = \frac{\text{Roll Moment}}{\frac{1}{2}\,\rho\, V^2\, S\, d}$$